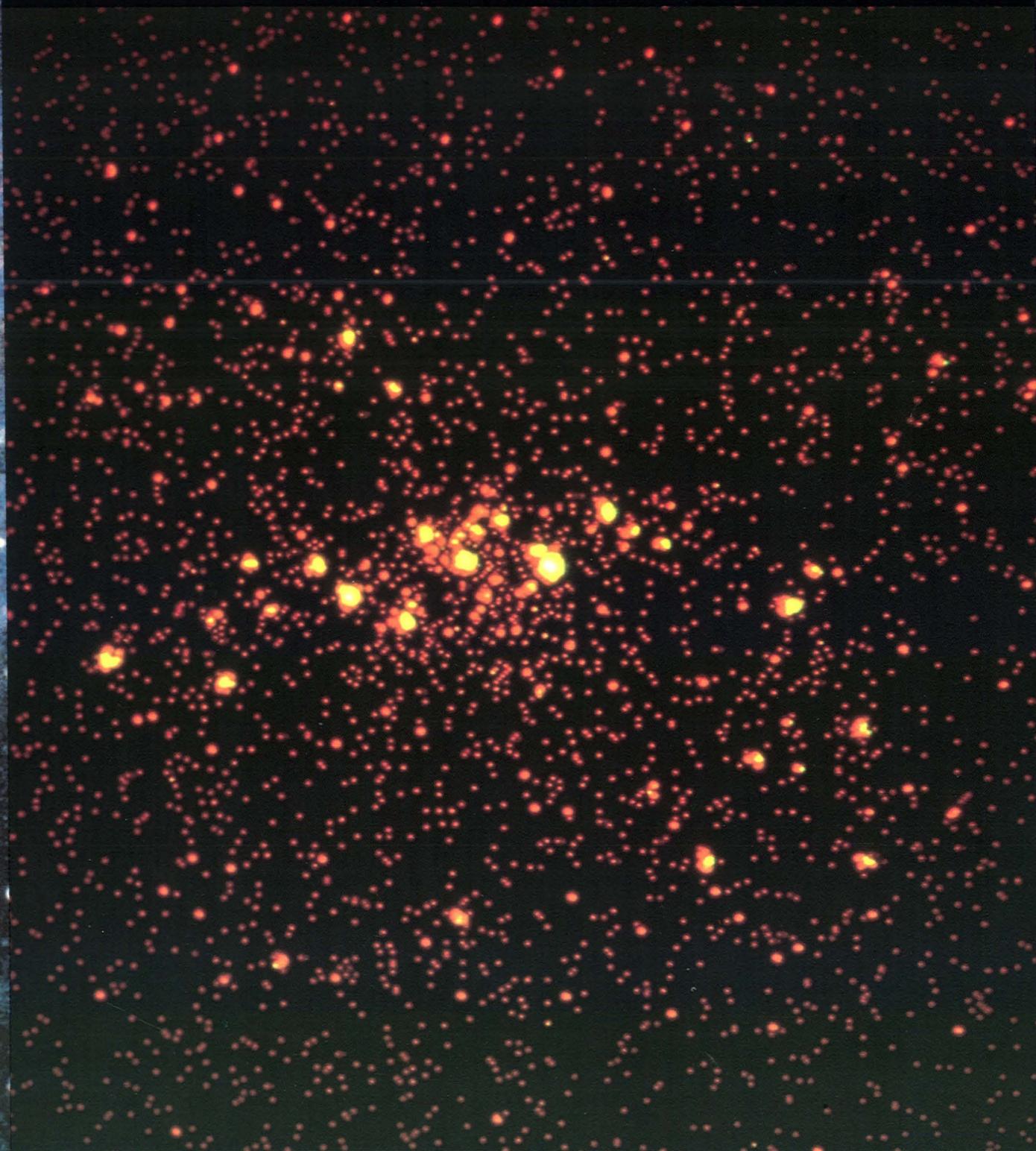


THE ADVANCED X-RAY ASTROPHYSICS FACILITY

# Observing the Universe in X-Rays



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THE ADVANCED X-RAY ASTROPHYSICS FACILITY //

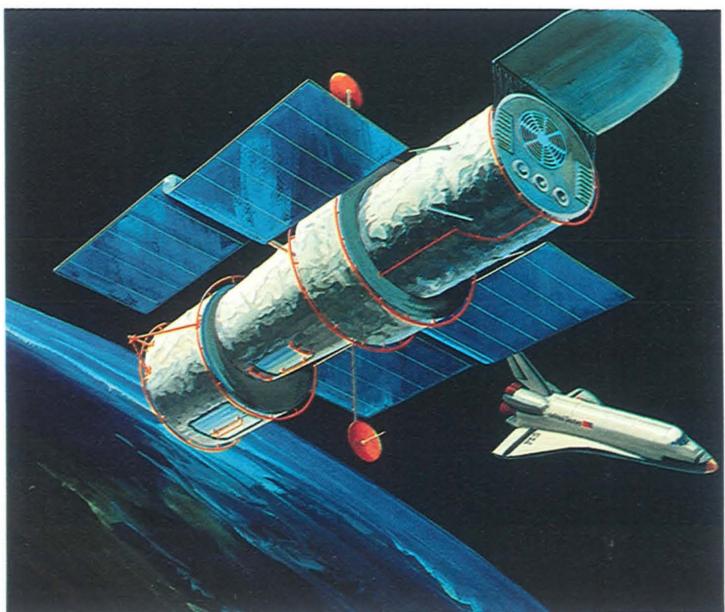
# Observing the Universe in X-Rays

NASA -EP- 199



National Aeronautics and  
Space Administration

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By Dr. Valerie Neal in collaboration  
with the Marshall Space Flight  
Center, the Office of Space Science  
and Applications and the Smithsonian  
Astrophysical Observatory.

**AXAF**

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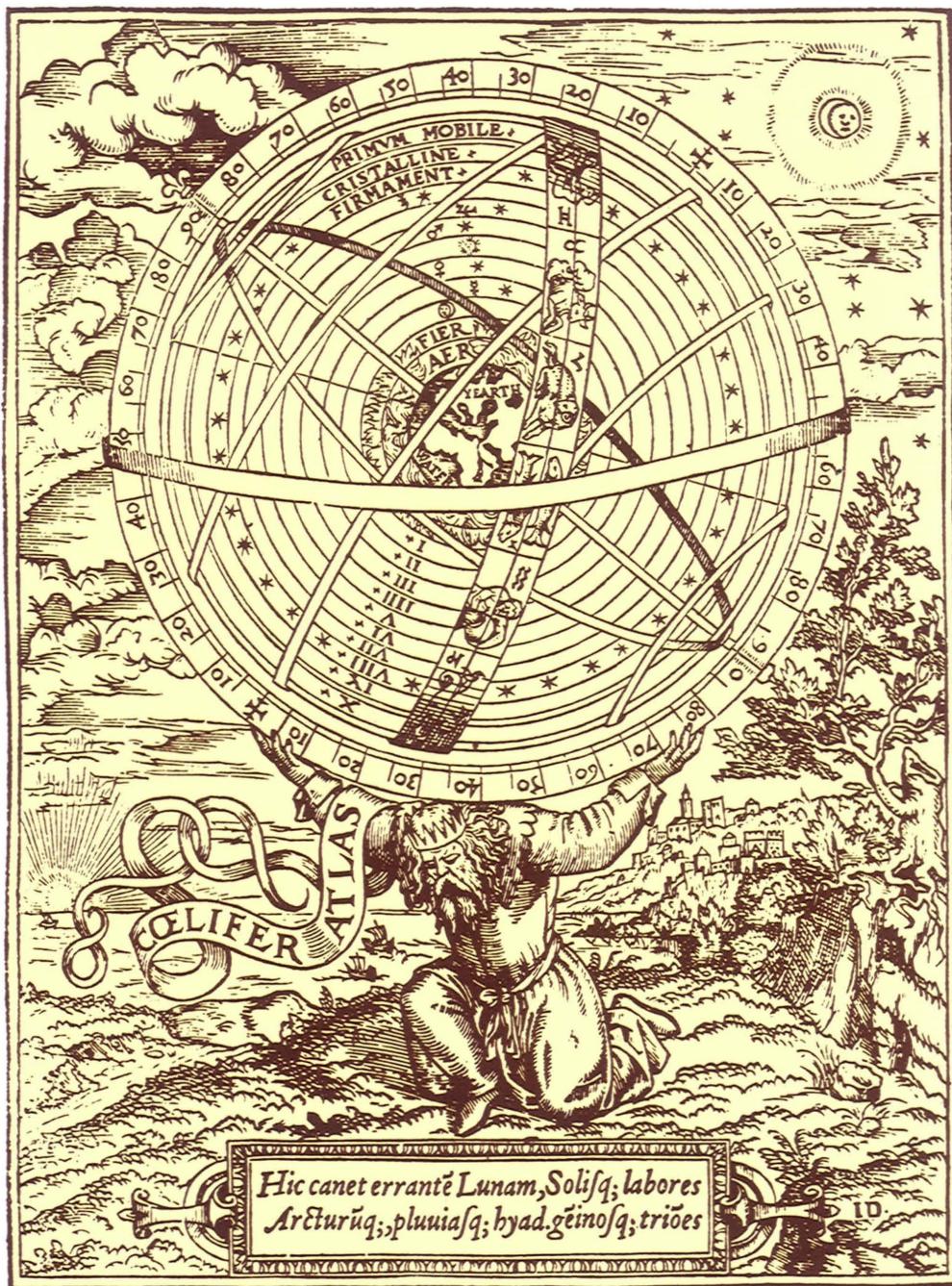
**A**s the last decade ended, an innovative orbiting telescope was focusing X-rays from distant celestial objects into images of unprecedented clarity and detail. Suddenly we could see more X-ray sources than we ever imagined to exist, and we saw the universe as a stage for dramatic high-energy events that cannot be witnessed by ordinary astronomy. X-ray

astronomy came of age, rich with promise for improved understanding of the universe.

Now X-ray astronomers are digesting data collected a few years ago, but little new information is being gathered. Our view of the invisible X-ray universe is fixed until a new and keener eye is opened.

The national strategy for astronomy research during the rest of this century is a coordinated, broad spectrum study of

the heavens. Advanced optical and radio observatories (Space Telescope and the Very Large Array) are already being developed. The highest priority new astronomy program is the Advanced X-Ray Astrophysics Facility (AXAF), an orbital observatory for detailed, long-term study of X-ray emissions and the phenomena that produce them. The AXAF is an essential step in our continuing quest to understand the universe. □



In this sixteenth-century engraving, the mythical figure Atlas bears a model of the universe as it was then known. The four elements – earth, air, fire, and water – are surrounded by the moon, sun, planets, and heavens. The circles bounding the universe represent the ecliptic, equator, tropic and polar zones, and the zodiac.

**W**e are stargazers. Since ancient times, we have studied the heavens, cataloguing the stars, noting seasonal variations in their positions, recording phases of the Moon, watching the Sun, devising calendars, and navigating by points in the sky. We have sought to understand the mysteries of our universe, its organization, origin, and fate. From our observations, we have constructed models of the universe and of our place in it.

Early concepts of the universe blended fact and myth; astronomy was inseparable from theo-

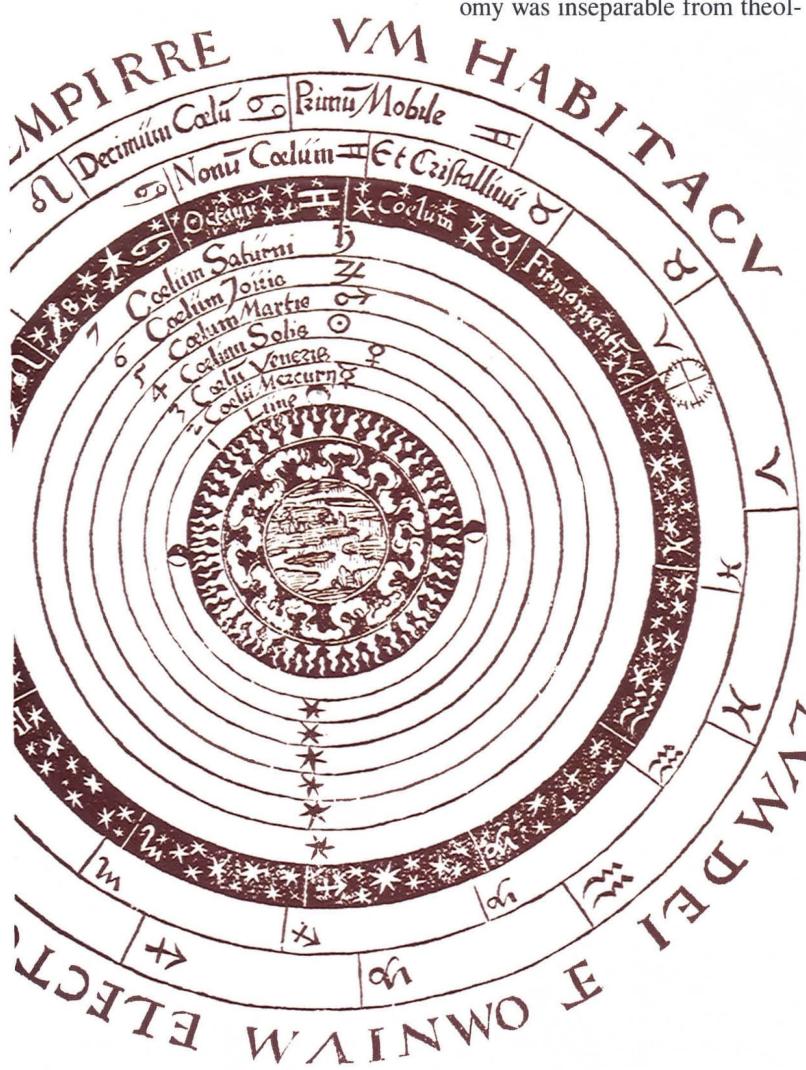
logy and philosophy. As we found ways to improve our view of the sky and to look deeper into space, our images of the universe changed. By the early seventeenth century, mathematics and the telescope forced us to abandon our view of an Earth-centered universe and acknowledge the Sun as central. We later realized, however, that our Sun was but one star in a vast galaxy of stars, and that our Galaxy was not the only one in space. We found ourselves in an inconceivably vast universe of galaxies, each one an “island universe.”

We recently realized that the universe is not a static, stable place. Modern scientists show us a dynamic, expanding, cataclysmic universe that spans unimaginable time and distance. The age-old image of a quiet, unchanging universe has been supplanted by the concept of a cosmos filled with turmoil and violence on a grand scale.

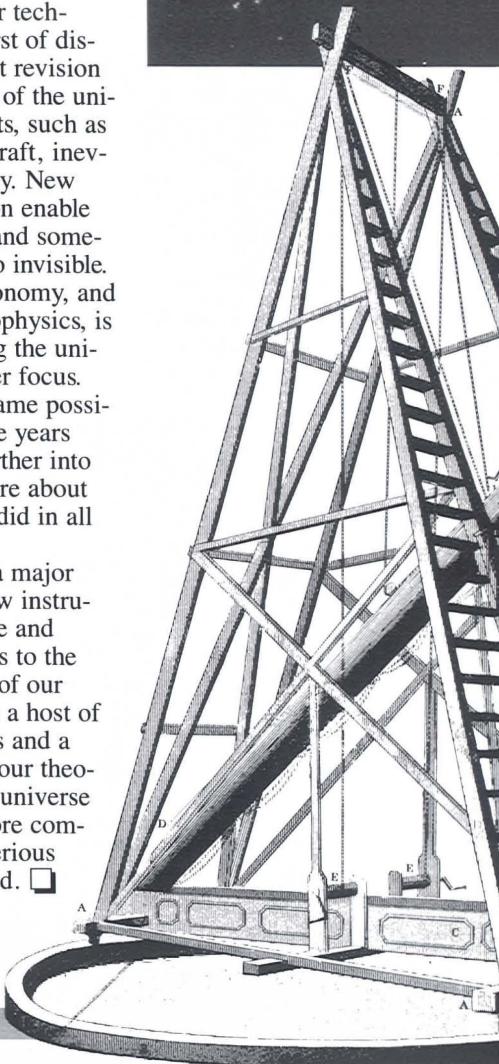
Virtually every advance in astronomical theory or technique stimulates a burst of discovery and subsequent revision of the reigning model of the universe. New instruments, such as telescopes and spacecraft, inevitably lead to discovery. New techniques of detection enable us to see and understand something that was hitherto invisible.

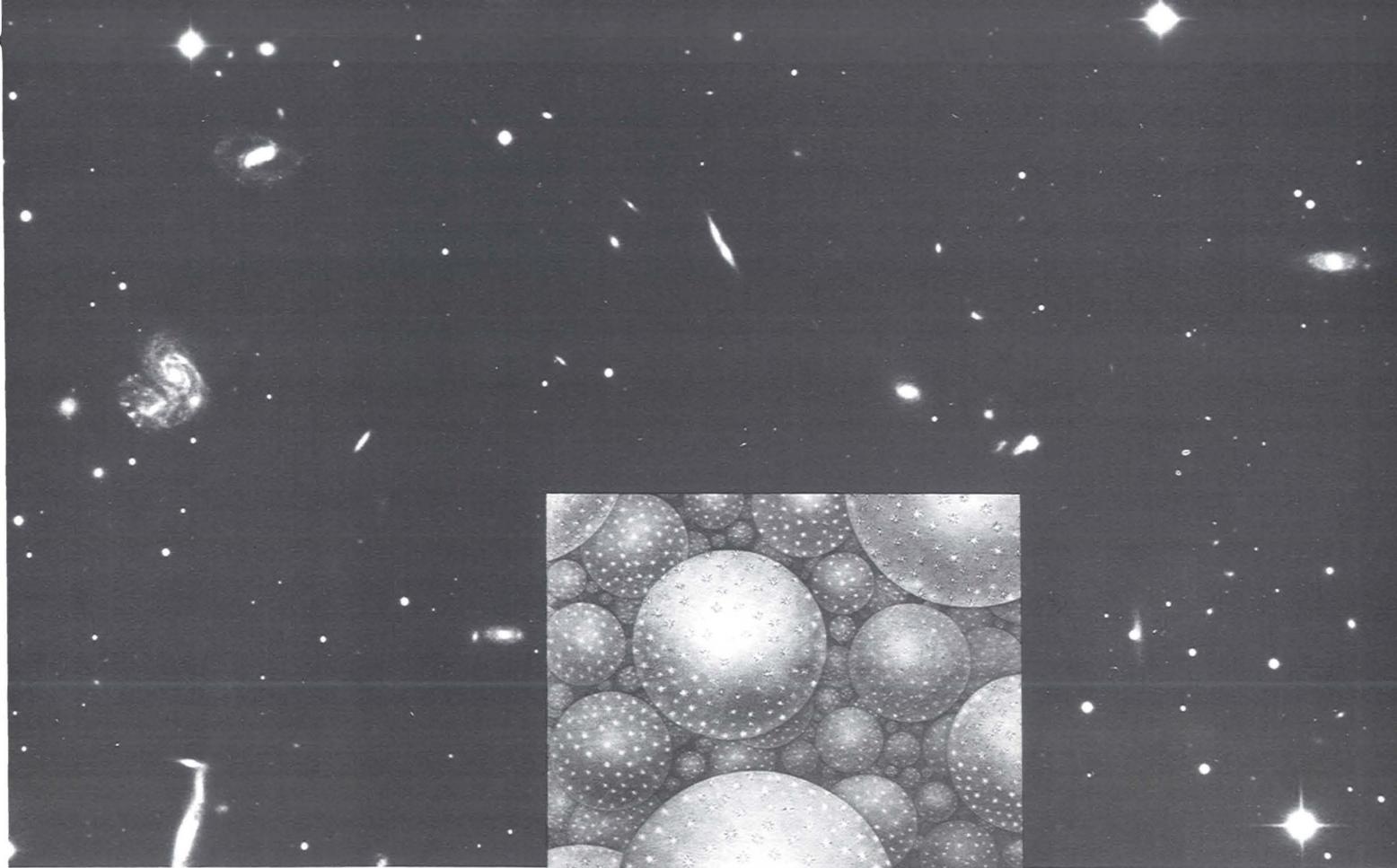
The history of astronomy, and more recently of astrophysics, is the history of bringing the universe into ever-sharper focus. Since spaceflight became possible a mere twenty-five years ago, we have seen farther into space and learned more about the universe than we did in all of human history.

NASA has played a major role in developing new instruments for use in space and opening new windows to the universe. The results of our recent discoveries are a host of unanswered questions and a continual revision of our theories and models. The universe looks even vaster, more complex, and more mysterious than we ever imagined. □

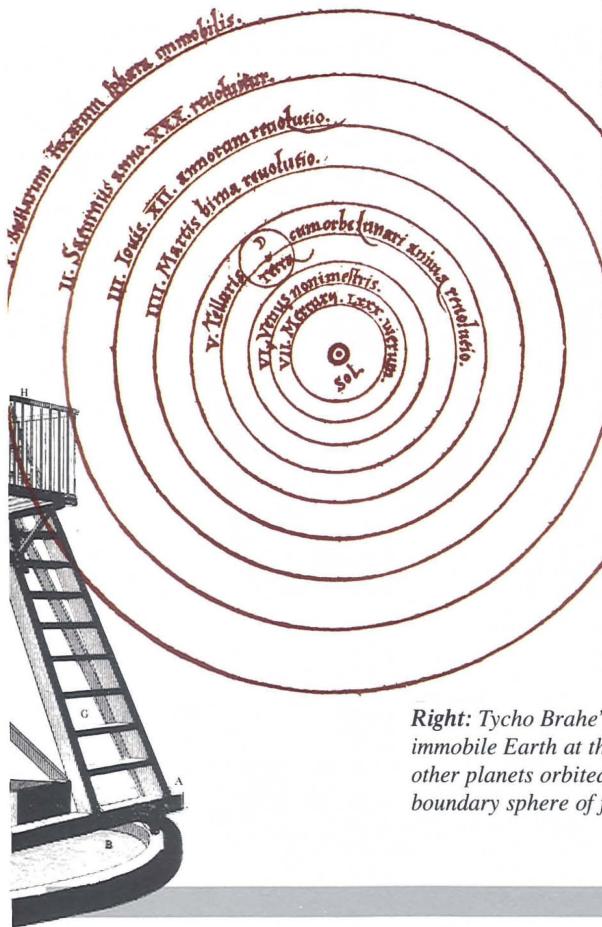


According to Aristotle and Ptolemy, the center of the universe was the Earth, orbited by the moon, sun, and five planets. The ancient Greeks imagined the universe as a series of concentric, transparent spheres enclosing the planets and stars. The outermost “primum mobile” controlled the motions of all the spheres. This model prevailed in Western thought from antiquity until the Renaissance.



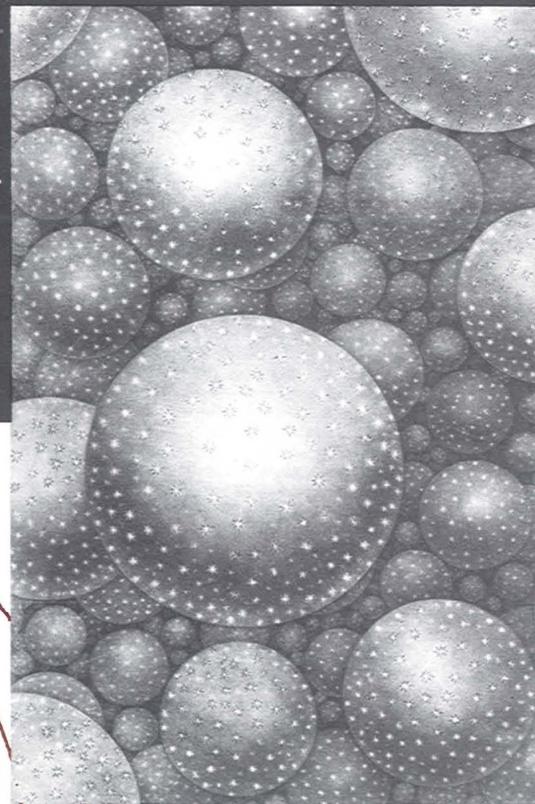


*Above:* A cluster of galaxies in the constellation Hercules.

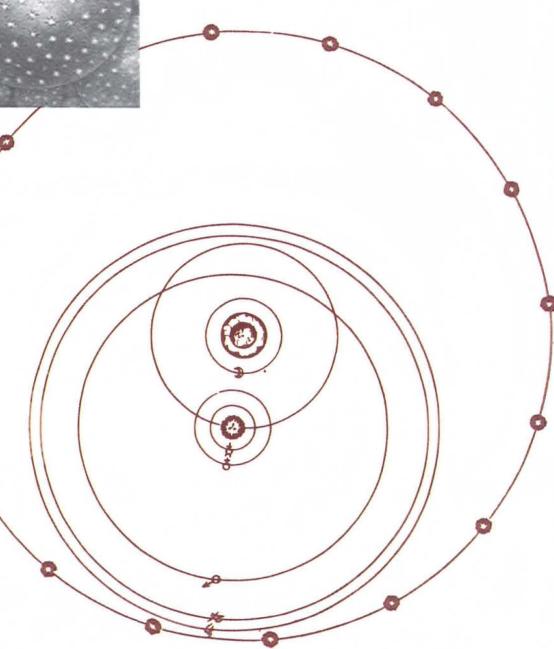


*Left:* In the Copernican model of the universe, the central sun was surrounded by the planets and the realm of fixed stars.

*Right:* Tycho Brahe's sixteenth-century model showed an immobile Earth at the center of the universe while all the other planets orbited both the Earth and the Sun within a boundary sphere of fixed stars.



*Left:* When the telescope revealed the multitude of stars and the vastness of the heavens, the universe could be imagined to consist of many systems similar to our own solar system. In this illustration, published in 1750, the universe no longer appears bounded.



We learn about the universe by studying the quality and quantity of energy emitted by celestial objects. For most of history, astronomy has been the study of visible starlight. Visible light, however, is only a very small fraction of the electromagnetic energy emitted by celestial sources. The rest consists of radio waves, infrared and ultraviolet radiation, X-rays, and gamma rays.

The Earth's atmosphere is a veil that absorbs most of this radiation before it can reach telescopes and detectors on the ground. The atmosphere is transparent only to visible light and some radio emissions. Higher energy radiation, such as X-rays, does not penetrate and thus cannot be detected from the ground.

The space program has revolutionized astronomy by placing observational instruments outside the filtering atmosphere. During the past three decades, we have been able to look at the universe through these new "windows." The X-ray region of the spectrum has proved to be a very rich source of information, full of surprises about the

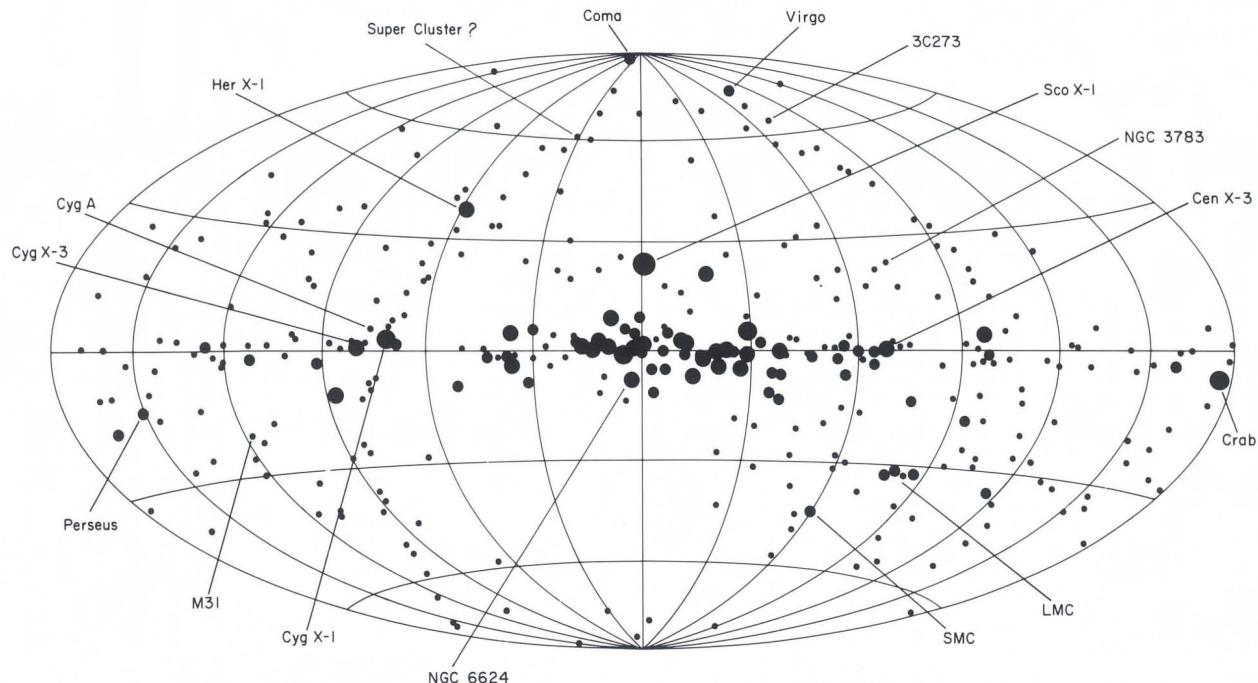
nature of our universe. The universe as we know it now is punctuated by explosive phenomena associated with the birth and death of stars. When cosmic explosions occur, gases are heated to millions of degrees and matter is accelerated to extremely high velocities. Much of this explosive energy is released as high-energy radiation, X-rays.

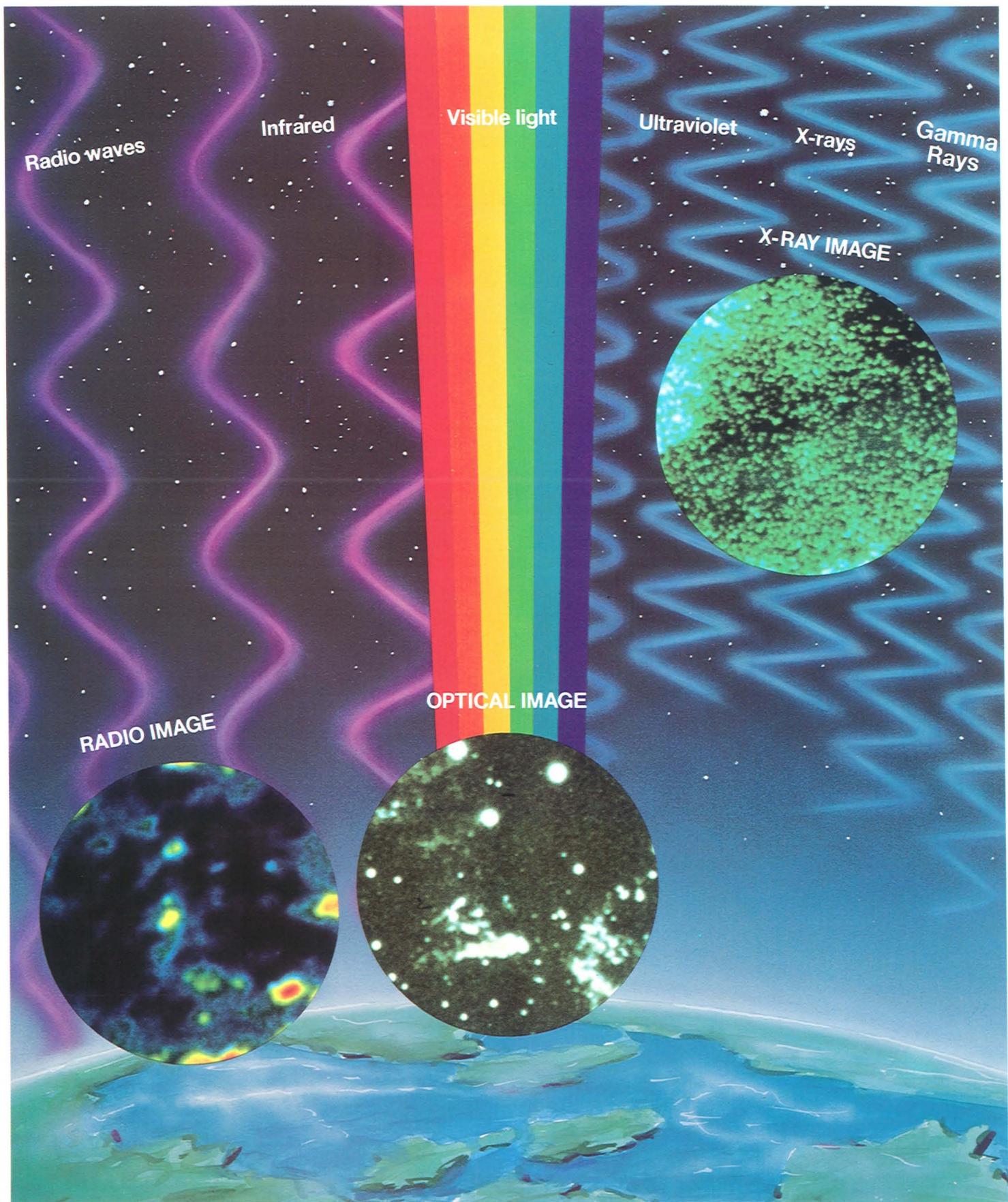
Because a tremendous amount of energy is required to create X-rays, we know that wherever they are observed something violent has happened. X-ray emissions carry detailed information about the temperature, density, age, and other physical conditions of the celestial objects that produce them. The study of these emissions (X-ray astronomy and astrophysics) provides insight into many of the fundamental physical processes that govern the universe.

The sources of copious X-rays are some of the oddest and most fascinating objects in the sky. They include spinning neutron stars so dense that a drop of neutron material can weigh as much as the combined weight of all the people on Earth. Through X-ray observa-

*Right: Observations in different regions of the electromagnetic spectrum yield quite different pictures of celestial objects. By looking through more than one of these "windows," we gain more complete information about the universe. Because X-rays do not penetrate the Earth's atmosphere, X-ray images must be obtained from telescopes in space.*

*A map of the sky in galactic coordinates shows approximate locations of about 325 X-ray sources known in 1978. In the 2½ years of HEAO operations, the number of identified X-ray sources grew dramatically to almost 10,000.*





tions, astronomers have detected and studied what may be one of the remains of stellar explosions—the black hole, an object that has collapsed, leaving a “hole” in space from which nothing, not even light, can escape. Other X-ray emitters are galaxies and the mysterious quasars, the most powerful energy sources in the universe.

Since the first X-ray observation in 1962, a five-minute glimpse from the tip of a rocket, American scientists have used a half-dozen satellites for limited surveys of the X-ray sky. Each launch has resulted in dramatic discoveries. The most successful mission was the second High Energy Astronomy Observatory (HEAO-2), also called the Einstein Observatory, which operated in orbit from 1978 to 1981.

HEAO-2 extended and sharpened our view of the universe. It not only discovered many new X-ray sources, almost quadrupling the X-ray catalog; it provided, for the first time, actual images of these celestial objects, enabling us to see with X-ray sensitive eyes a beautiful but ordinarily invisible dimension of

the sky.

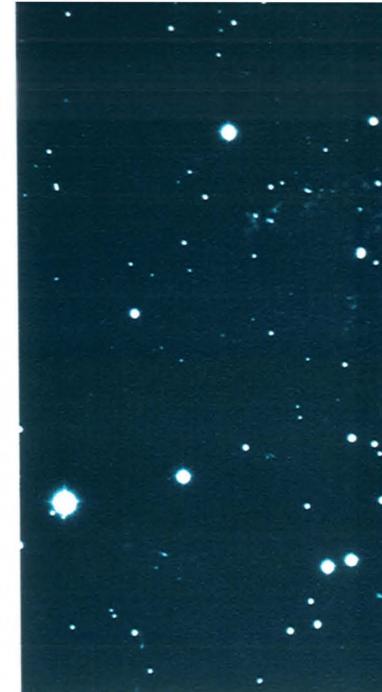
Results from X-ray surveys to date have been spectacular. We have located nearly 10,000 X-ray sources in our Galaxy and elsewhere, as well as a background glow of mysterious origin. We have obtained suggestive evidence for the existence of black holes. We have recognized the variable, fluctuating character of phenomena in our universe. The X-ray sky is an intricate and everchanging mural.

Now all known classes of celestial objects have been observed to emit X-rays. We have intriguing information about a variety of X-ray sources within our own Galaxy—supernova remnants, pulsars, neutron stars, black holes, and bursters. We also have first images of X-ray sources in galaxies beyond the Milky Way, including quasars more than 10 billion light years away, the most distant celestial objects yet observed. These data are helping us answer some of the basic questions of modern astronomy: How were these extremely high-energy emissions generated? How did the universe evolve? Is

the universe open or closed, forever expanding or not?

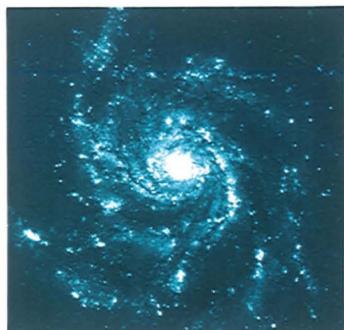
Stunning as recent X-ray observations have been, they amount to a mere glimpse of the universe compared to astronomical observations in other regions of the spectrum. There are probably many more sources of X-ray radiation than we have yet had the opportunity to see, and no doubt they are rich with new information about the universe. We have barely tapped this exciting and important new resource, for the instrument has not been flown that can see far enough, sensitively enough, and long enough for detailed X-ray studies of the sky.

We are now ready to advance to the next step in X-ray astronomy: from the brief, pioneering observations recently completed to a long-term, highly sensitive orbiting observatory equipped with the most sophisticated instruments available. The Advanced X-Ray Astrophysics Facility is a natural outgrowth of the past three decades of research, and it is a unique opportunity for continued astrophysical research through the end of this century. □



*A massive star exploded in the constellation Cassiopeia, probably in the late seventeenth century. Today only dim wisps of gas are visible through an optical telescope, but this remnant has been identified as an intense radio source.*

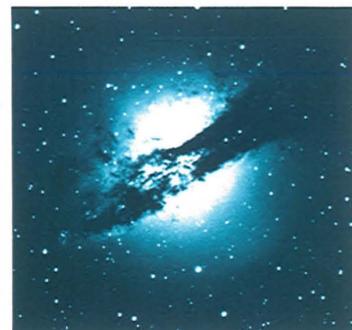
X-rays are emitted by extremely hot stars and violent explosions. Several classes of celestial objects are sources of X-rays. Invisible black holes also produce intense X-ray emissions.



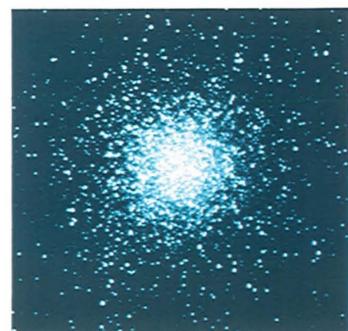
Normal Galaxy



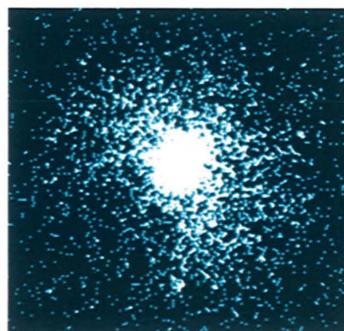
Active Galaxy



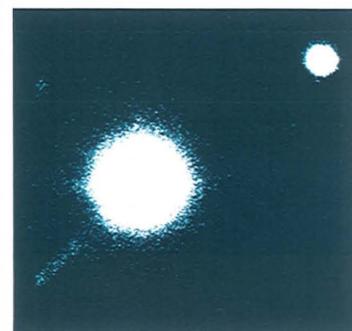
Radio Galaxy



Globular Star Cluster

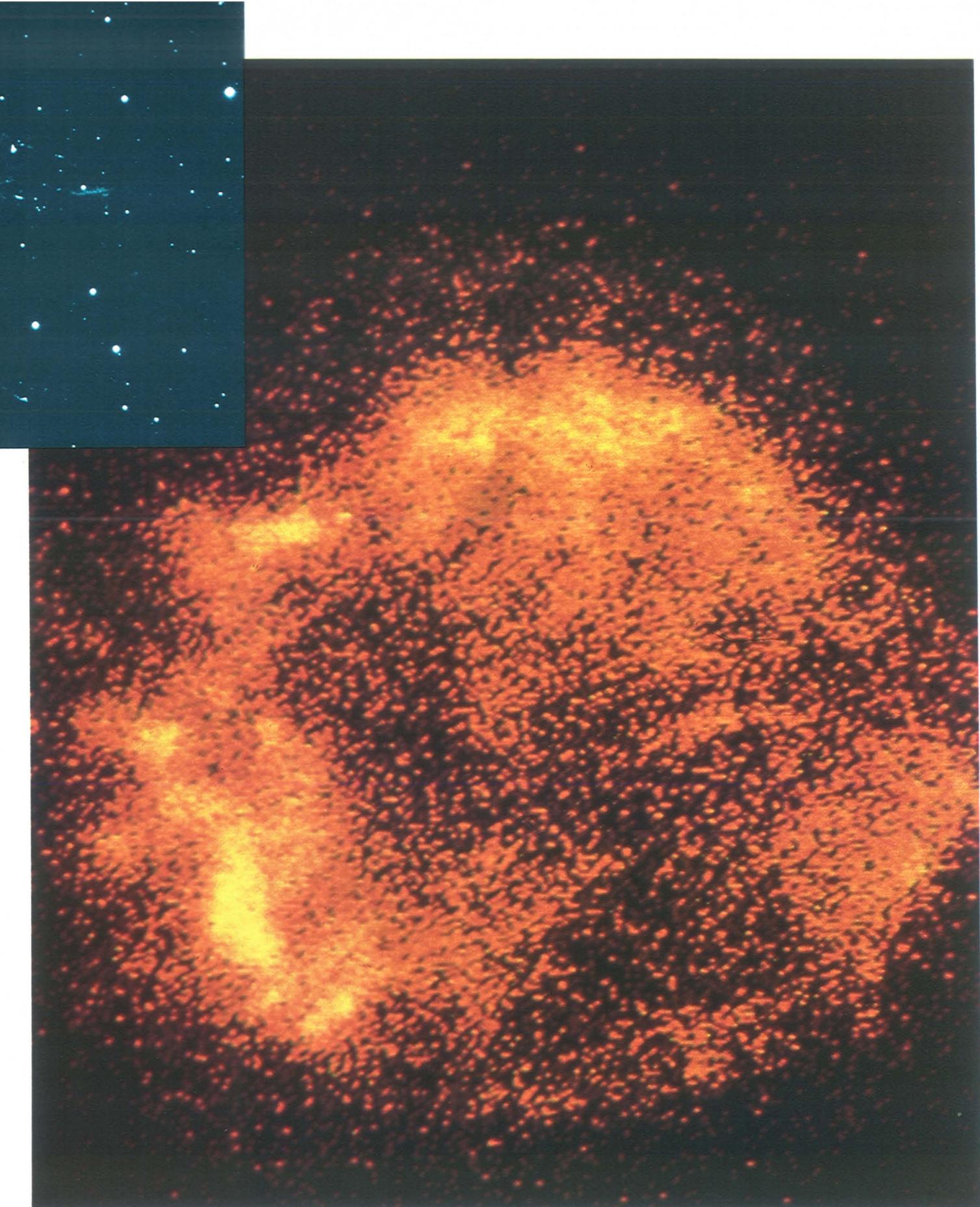


Supernova/Pulsar



Quasar

*Right: Cassiopeia A is also a source of X-rays. Through an X-ray telescope, the supernova remnant is quite conspicuous. A circular shell of hot gas and stellar debris is still expanding into space three centuries after the star's explosion.*



## AXAF – A New Observatory in Space

The Advanced X-Ray Astrophysics Facility is an observatory that will be carried by the Space Shuttle into Earth orbit at an altitude of about 288 miles (463 km). The eye of the AXAF is a large-area, high-resolution X-ray telescope. The telescope focal plane is equipped with instruments for detection, spectral analysis, and imaging.

The AXAF telescope is an enlarged, improved model of the grazing incidence telescope used so successfully on the HEAO-2 mission. X-rays striking a surface directly can easily pass through or be absorbed in most materials. However, if X-rays strike a very smooth surface at a very shallow angle, barely grazing the surface, they can be reflected and focused. Unlike optical telescopes that focus visible light with mirror discs, the AXAF X-ray telescope uses concentric, cylindrical mirrors with highly polished inner surfaces. Incoming X-rays strike these surfaces and are brought to a focus approxi-

mately 33 feet (10 meters) from the cylinders.

The AXAF will, of course, contain a full complement of instruments for studying various properties of X-ray emissions. These instruments will provide superior space, time, and energy resolution and sensitivity to polarization - all of which will yield more detailed information about X-ray sources than previously possible. Images and scientific data will be converted to electronic signals and transmitted to Earth for processing and analysis.

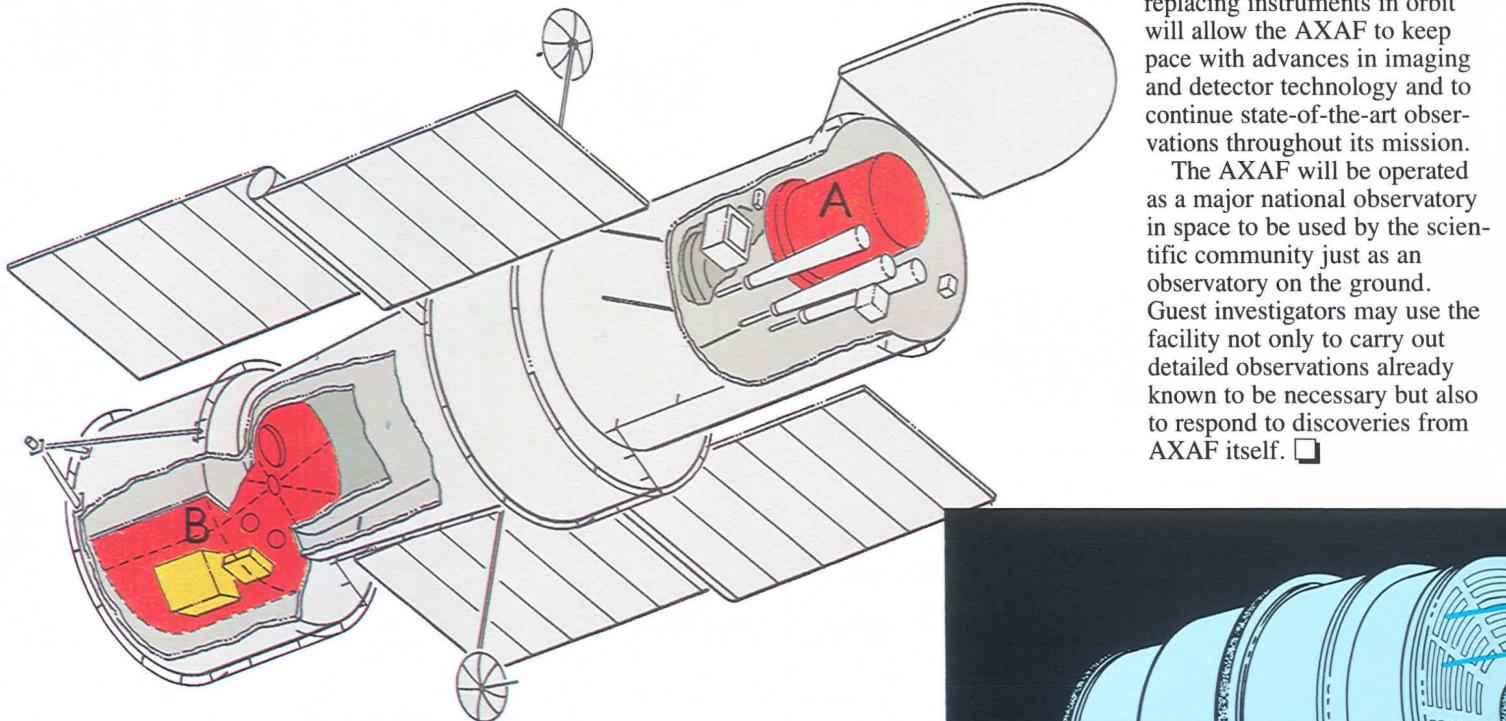
The AXAF is a significant advance over the moderately sensitive Einstein Observatory, which studied only a fraction of the sky. The AXAF is 100 times more sensitive, with an eight- to tenfold improvement in resolution; this means that a larger region of the spectrum will be accessible for X-ray imaging and the resultant photographs will be superior to any now in existence. The AXAF thus provides increased sensitivity to lower X-ray energies and extends X-ray imaging to higher

energies, where new results await us. The AXAF will allow, for the first time, a detailed study of all known classes of X-ray emitting objects and newly discovered sources.

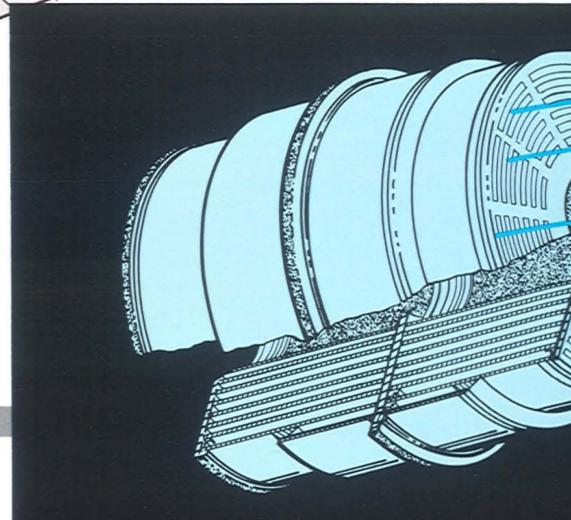
The AXAF will be the best X-ray observatory possible with today's technology. It will be able to detect, all the way across the Galaxy, objects with X-ray luminosities as small as 1% of the Sun's total luminosity, and it can study X-ray sources in hundreds of other galaxies as well. The AXAF will allow astronomers to locate X-ray sources with high accuracy for comparison with optical and radio observations. With its superior capability for detecting very faint, very remote sources, the AXAF may find some of the "hidden mass" of the universe, mass that has not yet been detected. We can anticipate many surprises.

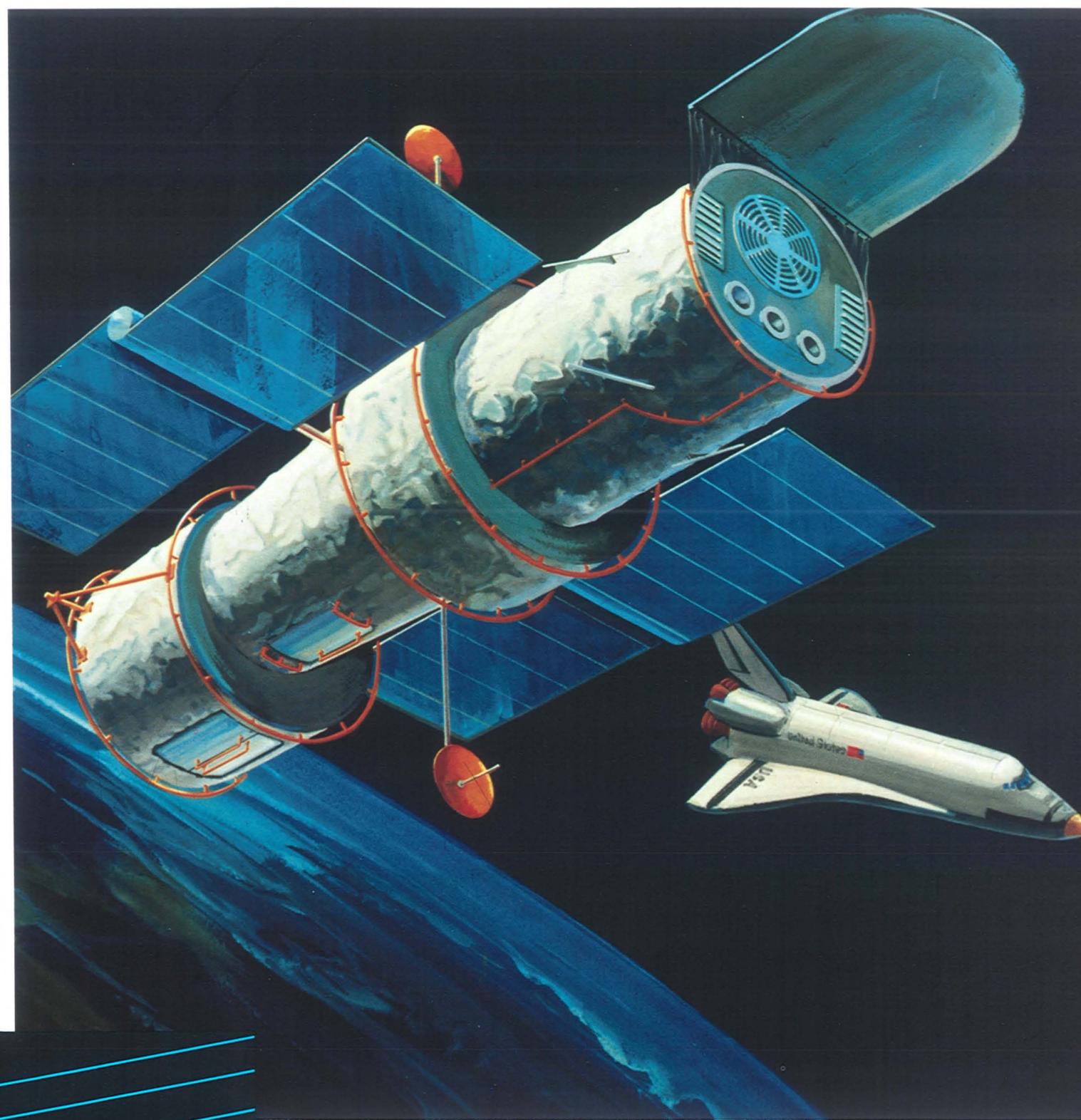
The design life of the AXAF is 10 to 15 years, compared to HEAO-2's lifetime of 2½ years. During its life, the AXAF will be visited by the Space Shuttle on service calls. Repairing and replacing instruments in orbit will allow the AXAF to keep pace with advances in imaging and detector technology and to continue state-of-the-art observations throughout its mission.

The AXAF will be operated as a major national observatory in space to be used by the scientific community just as an observatory on the ground. Guest investigators may use the facility not only to carry out detailed observations already known to be necessary but also to respond to discoveries from AXAF itself. □



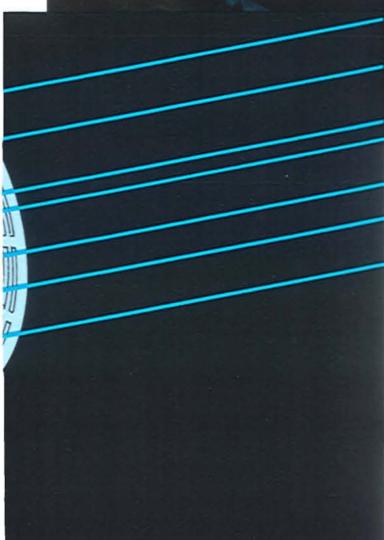
Above: The AXAF will be approximately 45 ft. (14 m) long and will weigh 10 tons (9100 kg). The facility is designed to house a mirror assembly (A), optical bench, and several focal plane science instruments (B) mounted on a carousel.





*Above:* The Space Shuttle will deliver the AXAF into orbit, visit it for servicing and repairs, and eventually return it to Earth. The AXAF is expected to operate for 10 to 15 years.

*Left:* Incoming X-rays are reflected by six nested pairs of cylindrical mirrors and brought to focus 33 ft. (10 m) away.



**D**espite recent advances in astrophysics, the universe remains veiled in mystery. Every discovery raises new questions. In the next few decades, the goal of astrophysics is to address as many of these questions as possible.

The Advanced X-Ray Astrophysics Facility is a versatile tool designed to probe the full range of celestial phenomena in search of answers. Among the myriad opportunities for AXAF research are studies of normal

stars and such exotic objects as black holes and quasars. The AXAF will be used for studies of many physical processes – heating and acceleration of gases, compression of matter, violent explosions. The AXAF will also be used to test cosmological models that describe the structure and evolution of the universe. We will learn more about the age, distance, composition, temperature, history, and dynamics of celestial objects. We will gain new understanding of what happens in the universe and why.

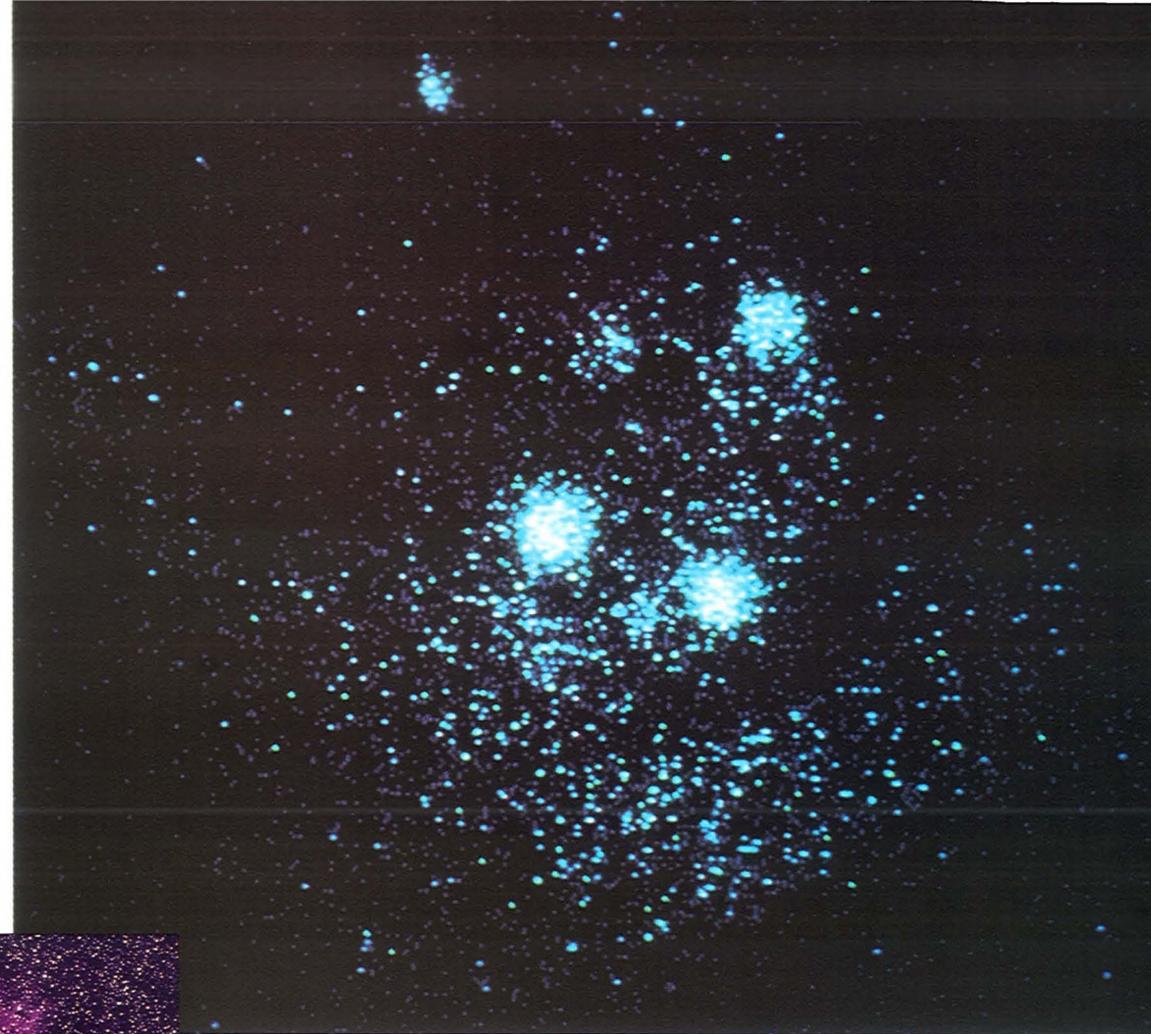
Its long lifetime and superior capabilities enable the AXAF to support this broad range of research efforts. Unlike any other X-ray instrument, this one can be used both to perform observations already planned and to follow up on its own discoveries. The potential growth of knowledge from AXAF teases the imagination: who can guess what new concepts of the universe will result from the rich yield of AXAF data? Let us briefly consider some of the phenomena within AXAF's view of the universe.



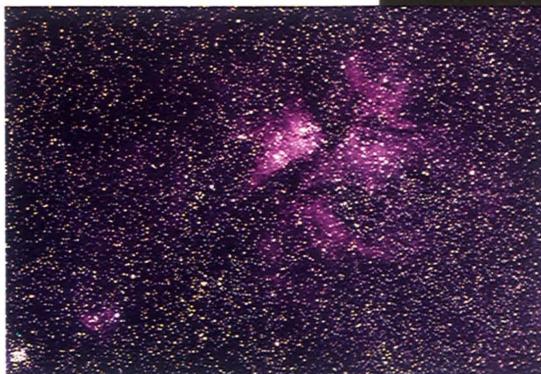
## Normal Stars

A major target of X-ray astronomy is the X-ray emission from familiar normal stars such as our Sun. Normal stars shine steadily and emit most of their energy as visible light. However, one of the most startling discoveries of the HEAO-2 mission was that many normal stars produce X-rays at much higher levels than suspected. This finding plays havoc with traditional theories of the heating of stellar atmospheres.

Further observations and new theoretical developments are required to explain these data. From the AXAF, we can study the atmospheres of many other stars in as much detail as we now study the Sun. From this work, we should gain a better understanding of stellar structures and processes. We may even find some "hidden mass" in X-rays emanating from faint, hot stars.



*Several X-ray sources are clearly visible in this HEAO image of Eta Carinae. X-ray imaging reveals many objects that are ordinarily invisible, as well as objects that are too faint to be detected optically or that are hidden by clouds of dust and gas.*



*Eta Carinae is a normal star surrounded by a glowing nebula, a dense cloud of gas and dust. Like a veil, this cloud absorbs radiation and obscures our view of the stars embedded in it.*



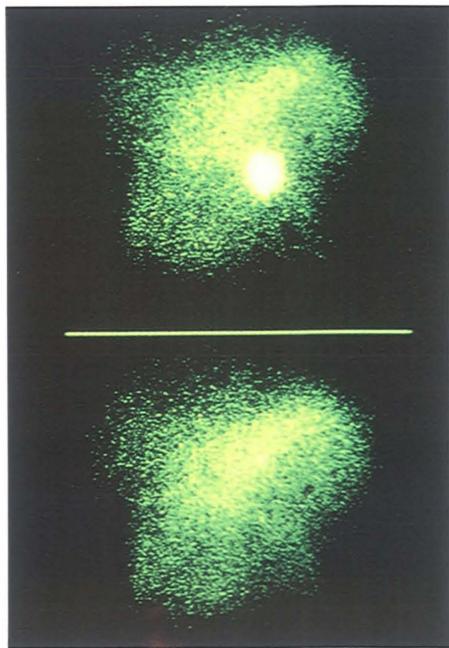
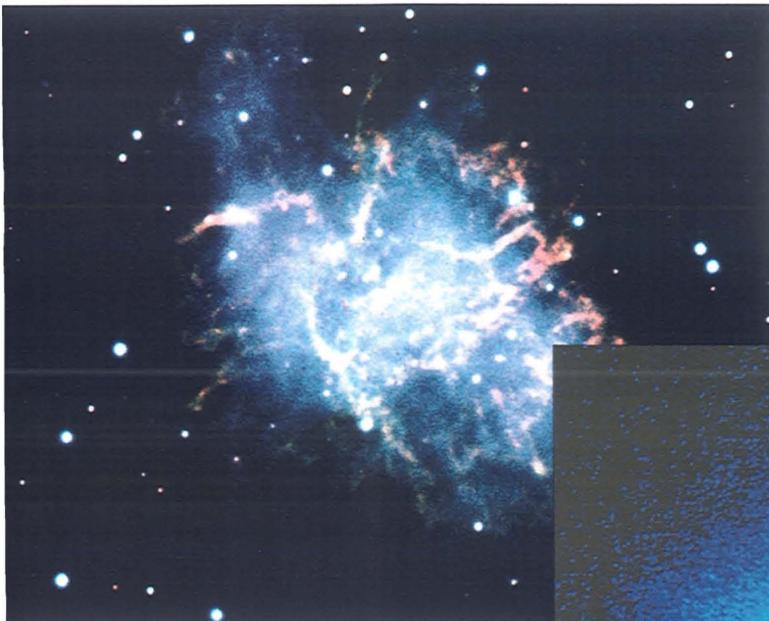
*Typically, X-rays are produced when the outer atmosphere of a normal star, such as those in the Hyades cluster, reaches a temperature of a million degrees or more. The exact details of this heating process are not yet understood.*

## Supernova Remnants and Pulsars

Over the course of eons, stars pass through a life cycle from birth to death. One of the final phases of stellar evolution may be a colossal explosion. Two or three times a century, a star in our Galaxy suddenly detonates, spewing gas and debris millions of miles into space. Sometimes

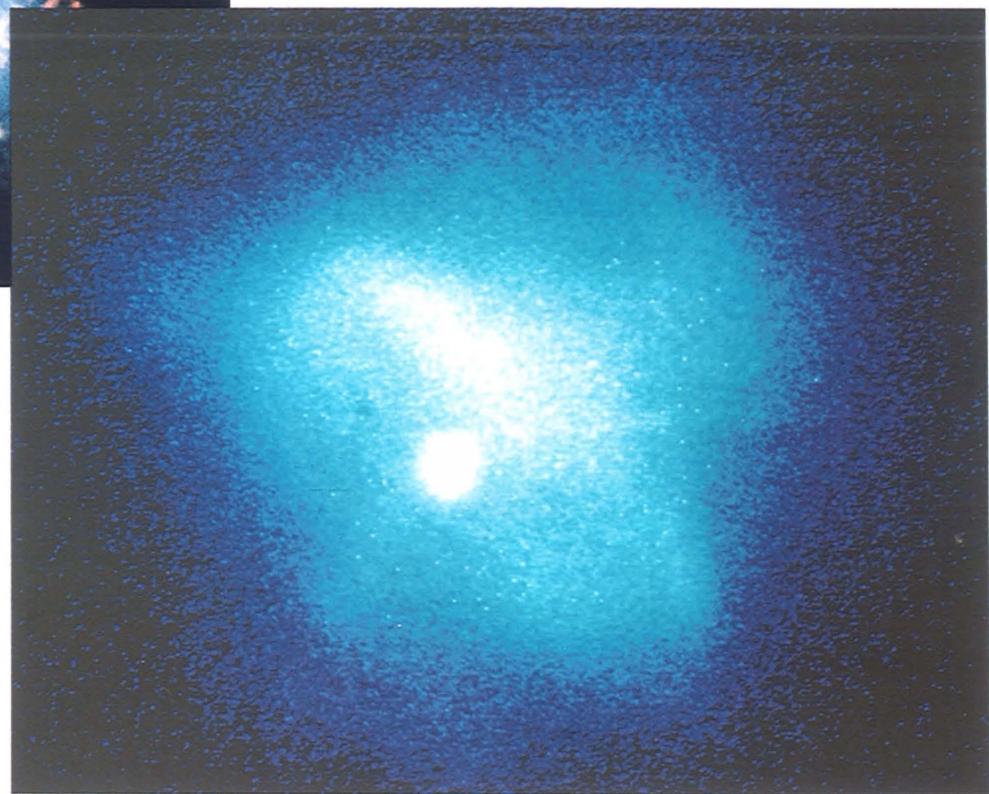
an exploding star, called a supernova, collapses into a dense, stable core; sometimes no central core remains. Some compact cores become pulsars, spinning neutron stars that emit pulses of radiowaves or X-rays; others do not. We cannot yet explain these differences.

With the AXAF, we can study stellar remnants, for the



An X-ray image of the Crab Nebula shows the surviving core of the exploded star. This core is now a pulsar, a spinning neutron star that emits regular pulses of energy.

The Crab Nebula pulsar blinks on and off 33 times per second. As the star rotates, its X-ray emission is channeled into a beam that sweeps through space like the beacon of a lighthouse.



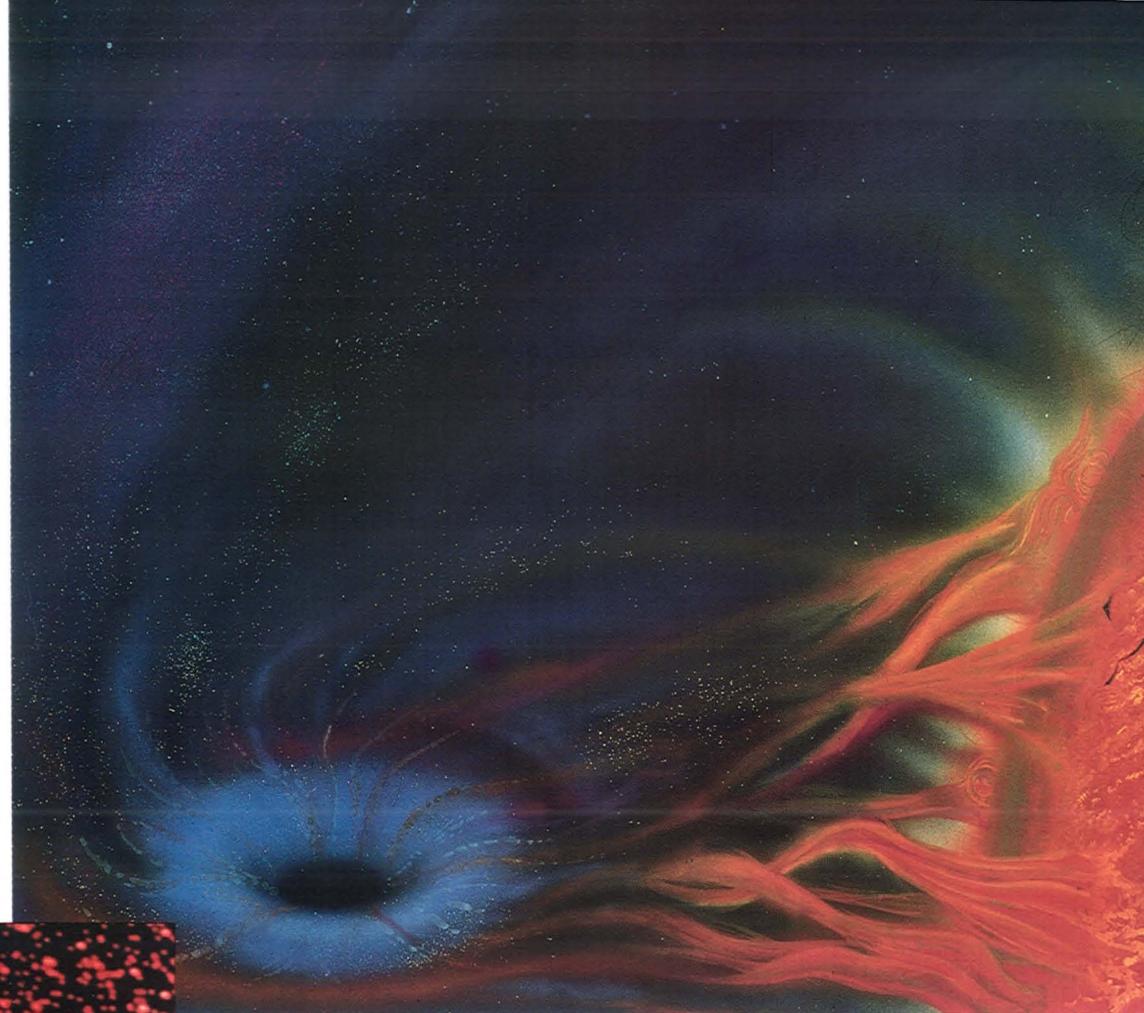
## Black Holes

One of the most imaginatively appealing concepts in high-energy astrophysics today is the black hole – a gravitational irregularity in space. Theoretically, a black hole might be created in this scenario. When a star about ten times more massive than our Sun enters the last stages of its life, an explosion occurs and the outer layers of the star are blown into space. The stellar core collapses under the force of gravity, and matter is squeezed into a point so dense and small that the star effectively vanishes from

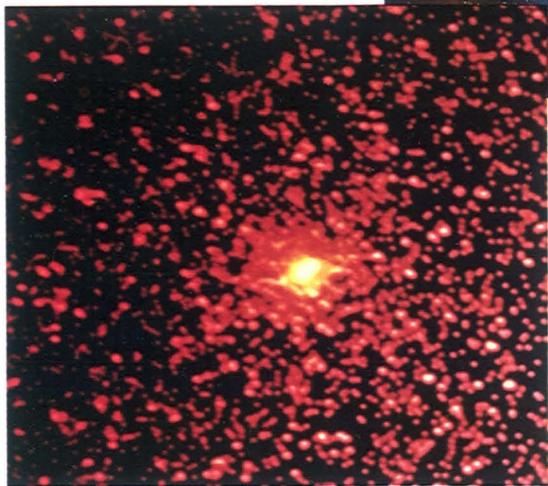
*Left: The Crab Nebula is the remnant of a stellar explosion observed in 1054 in the constellation Taurus. Then seen in broad daylight for three weeks, the supernova remnant is visible now only with the aid of a telescope. At its brightest, a supernova may shine with the light of 10 billion suns, briefly surpassing an entire galaxy in brightness.*

the universe through its gravity remains. The intensity of gravity above the surface of the shrinking star becomes so enormous that not even light can escape; hence the name "black hole."

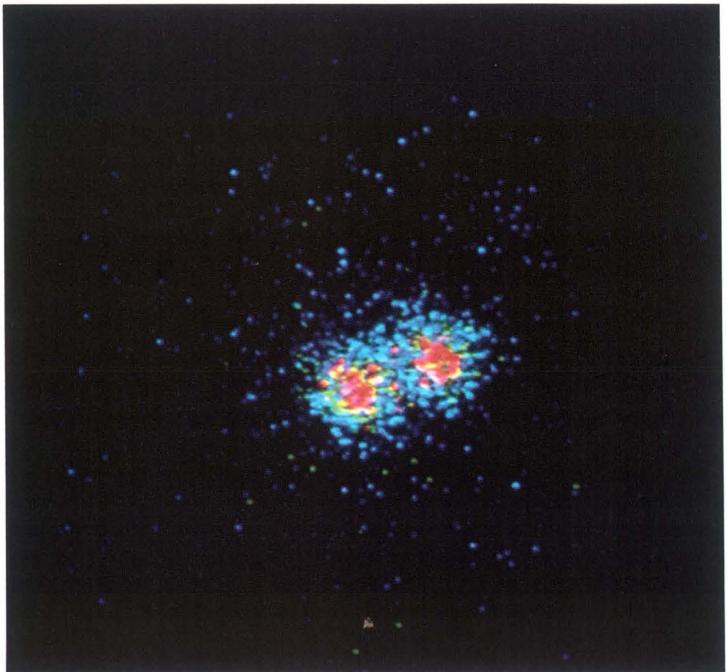
How then can we see it? If the black hole is part of a binary system (two stars circling each other), matter from the normal star can be sucked into the black hole. As gravity accelerates the matter before it disappears into the black hole, tremendous X-ray radiation is produced. To date, four candidate black holes of this type have been discovered by X-ray observations. The AXAF is capable of performing detailed studies of these objects to confirm or deny their black hole status. The AXAF can also search for more of these intriguing phenomena.



*Though a black hole is invisible, evidence of its gravitational effects on a nearby star may be observed. In this artist's concept, a black hole is portrayed as a cosmic whirlpool, sucking in matter from a nearby star. As matter from the companion star flows toward the black hole, it is heated so intensely that it produces copious X-rays, which can be detected.*



*An invisible object associated with a visible star in the constellation Cygnus is one of several possible black holes discovered through satellite observations. Cygnus X-1 is a powerful X-ray source with characteristics like those postulated for matter falling into a black hole.*



*Another candidate black hole is the giant galaxy (M87) in Virgo, a source of strong X-ray emissions. According to a current model, a supermassive black hole may be the hidden powerhouse in the core of an active galaxy, causing violent activity and unusually large emissions of energy.*

## Bursters

Among the most puzzling phenomena discovered in our Galaxy are X-ray bursters. These objects repeatedly produce sudden, intense bursts of X-ray radiation of incredible power, typically lasting only a few seconds. This short duration indicates that the object producing a burst must be very small; yet a typical burster releases more X-ray energy in those few seconds than the entire energy output of the Sun in a week.

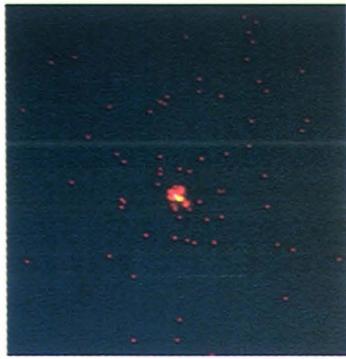
The exact nature and cause of the X-ray bursts are not yet known. They may arise from thermonuclear explosions on the



surface of a neutron star or from violent instabilities in the flow of material into a black hole. Many bursters are associated with globular clusters, spherical balls of hundreds of thousands of old stars. The AXAF, with its ability to locate precisely where within a globular cluster the X-rays emanate, can "weigh" the X-ray burster to determine whether or not it is a black hole. Detailed observations from AXAF should provide clues to the burster mystery.

## Galaxies and Clusters of Galaxies

Celestial objects are not evenly distributed throughout the universe. Instead, stars are



associated in galaxies, and billions of galaxies are scattered through space. Several different classes of galaxies have been identified, including "active galaxies" that produce enormous energy by some unknown process. As an X-ray source, our Milky Way Galaxy differs significantly from its nearest neighbor, the Andromeda galaxy.

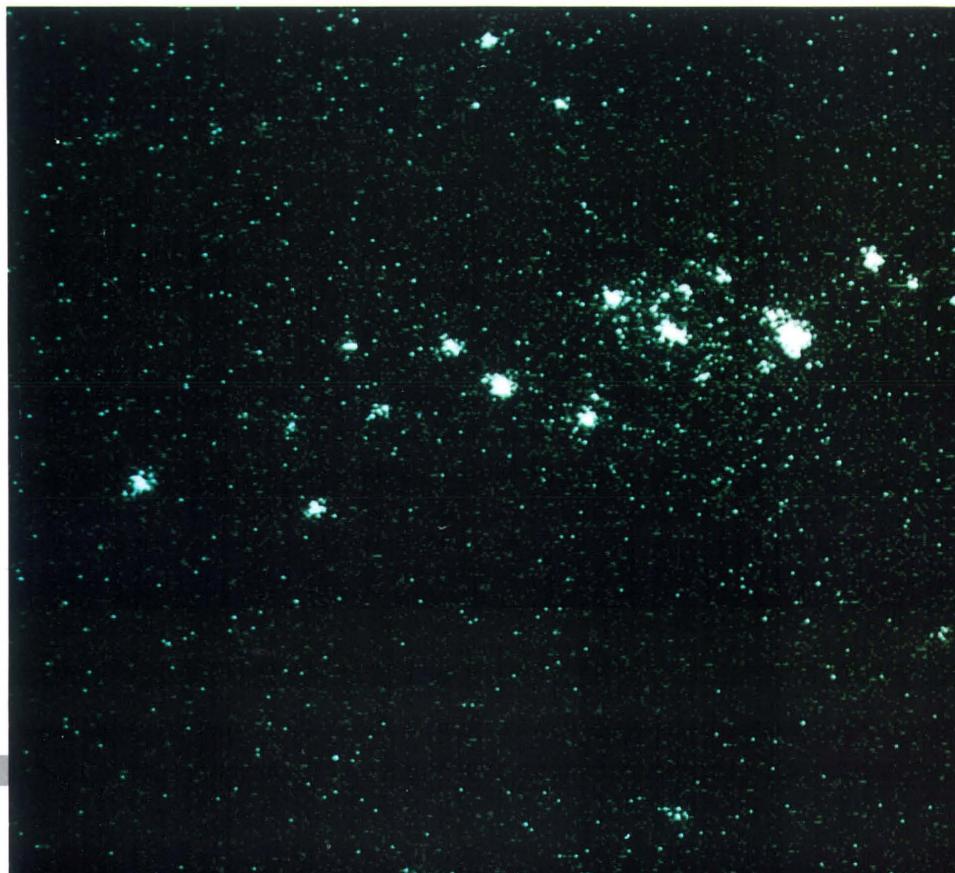
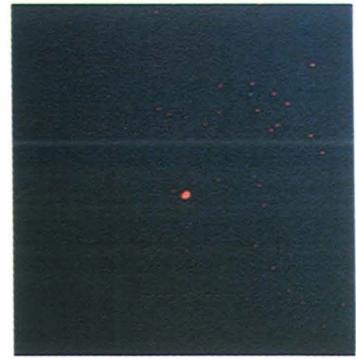
Though we do not yet understand all the differences among galaxies, we suspect that they pertain to galactic formation and evolution. The next step toward answering our questions is detailed X-ray observation of many other more distant galaxies. We also need a closer look

at the powerful nuclei of active galaxies to pinpoint the mysterious energy source there. These extragalactic studies are possible only with the AXAF.

Galaxies tend to cluster in groups ranging from a few to more than a thousand members. These clusters of galaxies are the largest aggregates of matter known to exist. We can chart and measure the total mass of clusters better by X-ray imaging than by any other technique because the space within them is filled with an extremely hot gas that radiates copiously in X-rays.

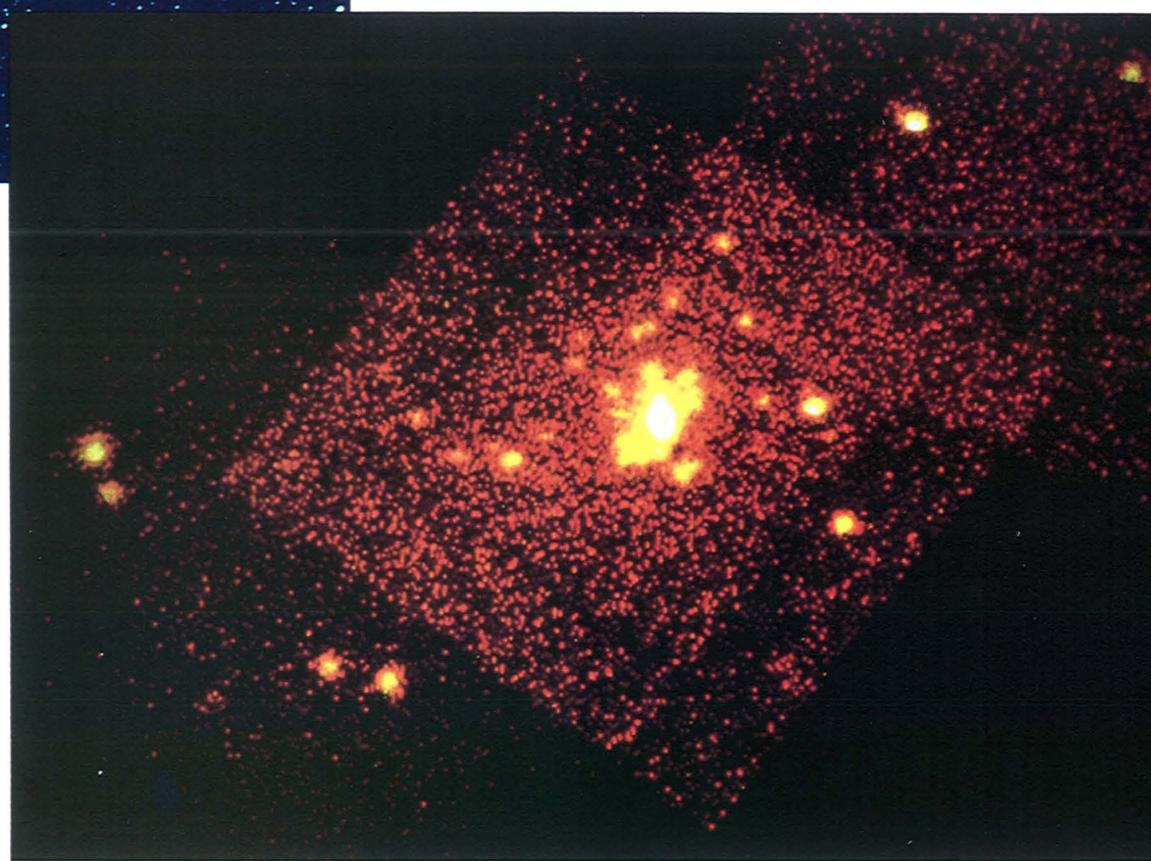
By studying the X-ray emissions of clusters of galaxies with the AXAF, astronomers hope to solve one riddle of their formation. Did clusters form directly from vast dust clouds early in the life of the universe and then fragment into galaxies? Or did the galaxies form first and later aggregate into clusters? AXAF observations are expected to provide new clues to the age and evolution of these huge celestial systems.

*Bursters are compact objects that display sudden, very intense increases in X-ray brightness. These images of a burster in the Terzan 2 star cluster were made immediately before, during, and after a burst that lasted about 50 seconds.*



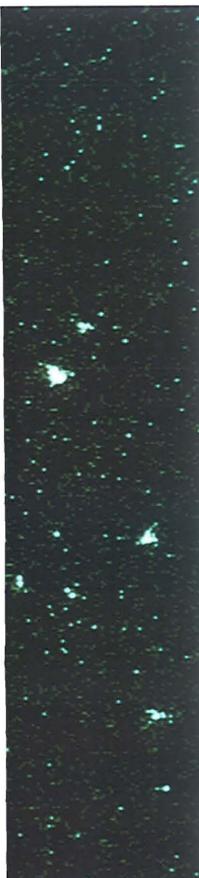


The Andromeda galaxy (M31) is the most distant object visible to the naked eye. A source of X-ray emissions, Andromeda is near enough for detailed comparisons with the Milky Way.



In visible light, Andromeda appears as a bright cloud of gas. Observed in X-rays, however, the galaxy is revealed as a collection of many X-ray sources. The concentration of X-ray sources at Andromeda's center is responsible for more than a third of the galaxy's total X-ray emission.

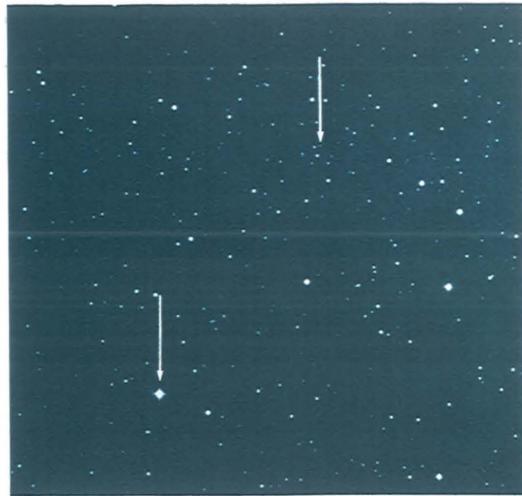
A high resolution X-ray image of the central region of Andromeda shows at least 20 X-ray sources. About 60 X-ray sources have been detected in the galaxy as a whole. The AXAF will produce images up to 10 times clearer and sharper than this HEAO-2 image.



## Quasars

Quasars are extremely luminous star-like objects believed to be located at the very edge of the universe. No larger than our own solar system, quasars are spectacular powerhouses that radiate more energy than an entire galaxy. Since light reaching the Earth from such distant objects must have started on its way in the remote past, the study of quasars is a way of probing the early history of the universe.

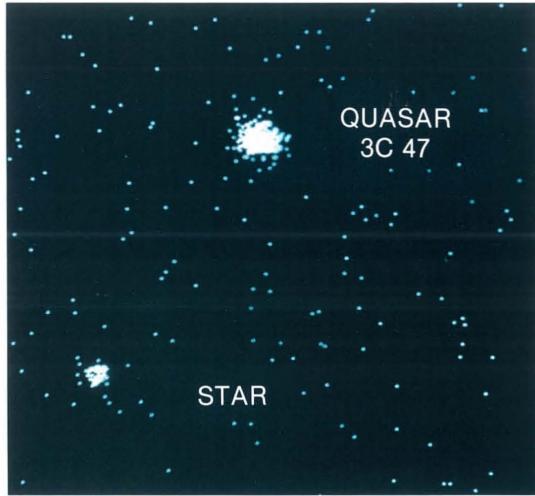
Despite much progress, we are still perplexed about the “engine” in a quasar that makes it the most concentrated source of energy in the universe. Some astronomers speculate that quasars may have at their centers a giant black hole at least a million times more massive than the Sun, with vast amounts of energy arising as stars are torn apart and swallowed by the black hole. Others think that quasars are immense concentrations of massive stars in the nuclei of active galaxies.



*Above, left:* In visible light, Quasar 3C47 is almost unnoticeable.

*Above, right:* In X-rays, however, the quasar appears far more prominent than its neighbors.

*Right:* Quasars are thought to consist of a tremendously powerful central source surrounded by whirling clouds of hot, radiant gas, as shown in this artist's concept.



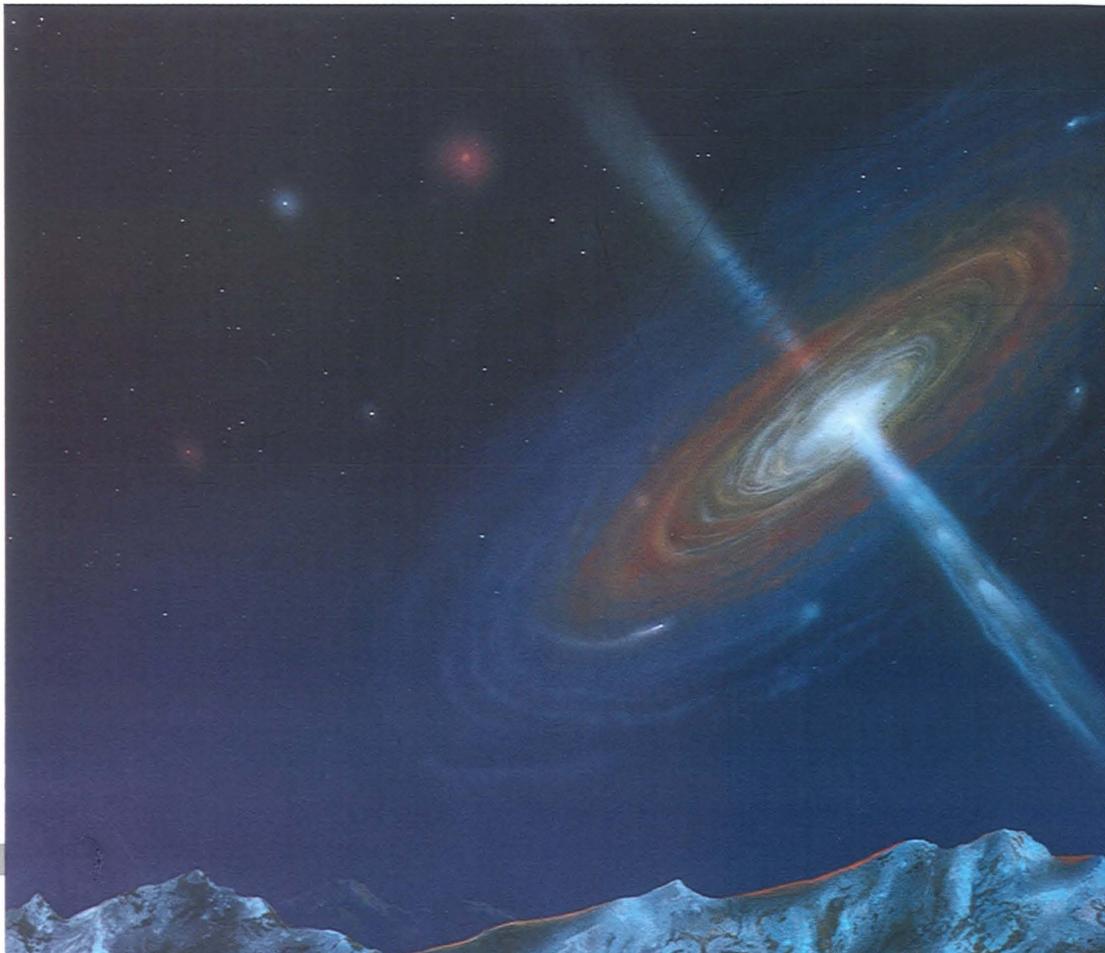
X-ray observation is one of the principal means for discovering and studying quasars. The sensitivity of the AXAF observatory will allow us to view thousands of quasars, looking back in time to the earliest stages in the formation of the universe. AXAF observations will also help us identify the violent process that powers a quasar.

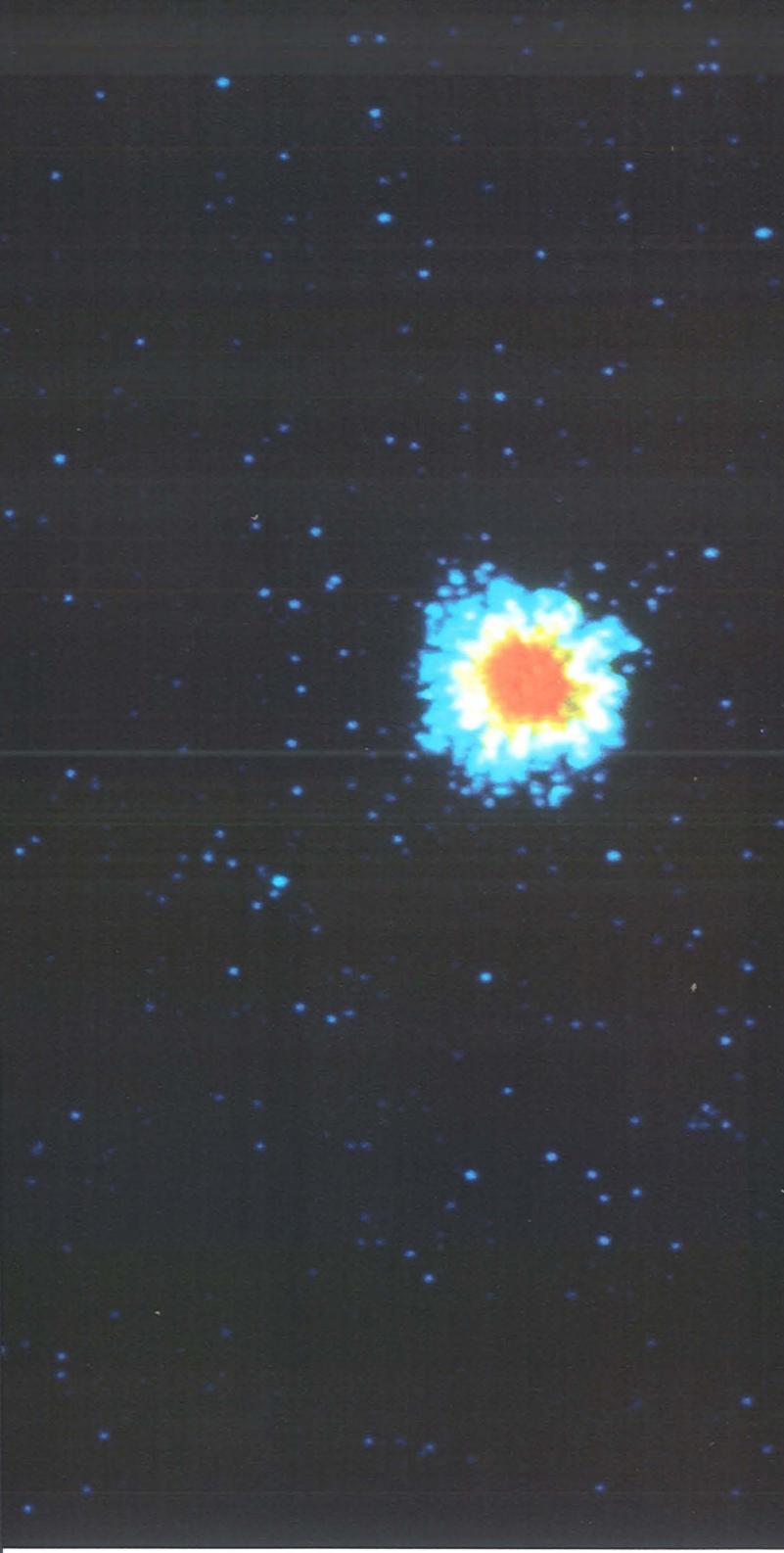
### The X-Ray Background

The earliest X-ray experiments made a discovery that has been the subject of deep interest

ever since: a low level of X-ray radiation pervades the universe. Although some of this X-ray radiation clearly comes from discrete objects in our own Galaxy, most appears to be extragalactic in origin. What causes this pervasive X-ray glow? Is it diffuse radiation from a hot gas distributed uniformly in intergalactic space, invisible in other wavelengths because of its high temperature? Or is it simply the X-ray radiation from countless extragalactic sources—galaxies, clusters of galaxies and quasars—that are indistinguishable with limited resolution X-ray detectors?

The most straightforward way to answer this question is to perform X-ray observations with the AXAF. We simply look with improved detectors deeper and deeper into space to observe and identify discrete X-ray sources. If these can account for the total emission attributed to the X-ray background, the question is answered. This answer is central to understanding the evolution—and ultimate fate—of the universe. □





*Above:* This X-ray image shows the familiar Quasar 3C273 (discovered in 1962) about 3 billion light years away and, in the upper left, the newly discovered Quasar 0Q172 (1979) at an estimated distance of 10 billion light years. These very remote objects represent the early history of the universe.

## The Universe: Open or Closed?

We now conceive of a dynamic, expanding universe, probably set in motion 10 to 20 billion years ago by a gigantic explosion. The energy and material generated by this "big bang" have been rushing outward since then. Some matter has coalesced into clumps of galaxies, stars, and planets, all propelled through space by the force of that ancient explosion.

Will this expansion ever end? There are at least two competing

answers, based on two different theoretical models—the closed universe and the open universe. Resolution of the question requires an accurate measurement of the entire mass of the universe. Astronomers must inventory everything in a feat of cosmic bookkeeping.

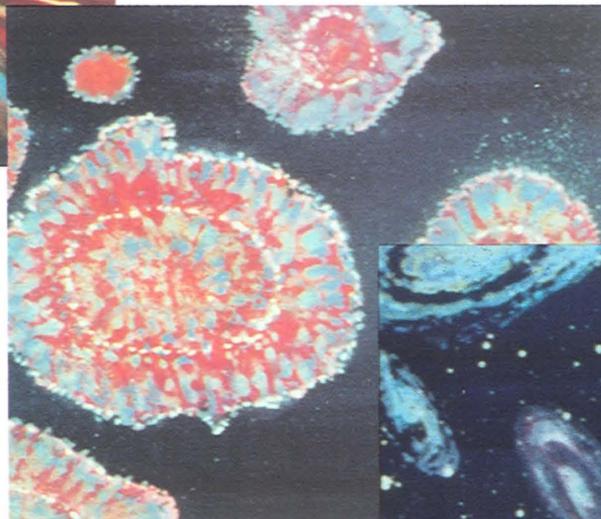
If enough material—stars, planets, dust, gas—exists, then eventually gravity will halt the outward rush and, in effect, close the door of the universe. Expansion may be followed by eons of collapse, until another explosion starts the cycle over again. On the other hand, if the mass account does not balance, expansion may continue infinitely in an open-ended universe.

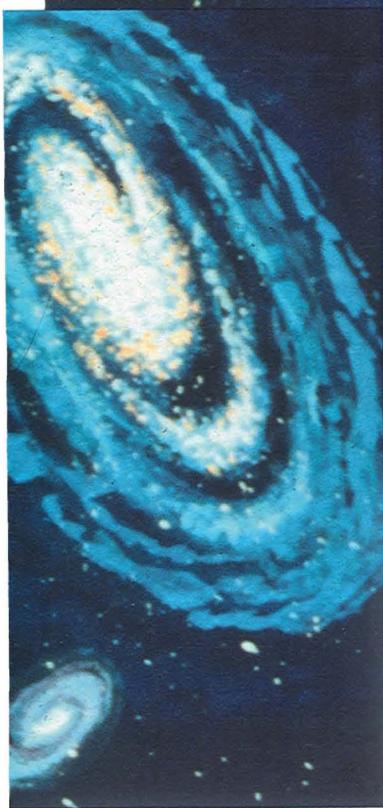
Observations in regions of the spectrum other than X-rays have

not found enough mass in the detected objects to close the universe. The X-ray background, possibly produced by a very hot invisible gas undiscovered by traditional astronomical techniques, may account for some of the missing mass.

However, much of what we once believed to be diffuse background radiation may be the product of quasars, observed just recently from the Einstein Observatory. Yet quasars may not be responsible for the entire background glow, and they do not provide enough additional mass to halt the outward expansion of the universe anyway.

So the challenging questions remain: Is the universe open or closed? Are there more exotic celestial objects yet to be discovered? Does the hot gas exist and, if so, how much mass does it contribute? These and other questions we hope to answer as the AXAF enables us to see farther into space and measure more precisely the curious objects we find there. □





*If the universe is “open,” it may expand forever. If it is “closed,” this expansion phase may reverse and the universe may undergo a prolonged collapse.*

## The Importance of AXAF

**T**he Advanced X-Ray Astrophysics Facility is planned to be a major national observatory shared by astronomers and astrophysicists. While we expect significant input to studies ranging from stellar evolution to cosmology, we also anticipate that results from the AXAF mission will spur technical and theoretical advances in a variety of other disciplines. Already X-ray astronomy has contributed to important developments in related fields.

For example, laboratory fusion research based on the generation and confinement of high-energy charged gases (plasmas) benefits from improved knowledge of natural plasmas found in the universe and from new instrumentation developed for X-ray astronomy. Scientists who study the myriad

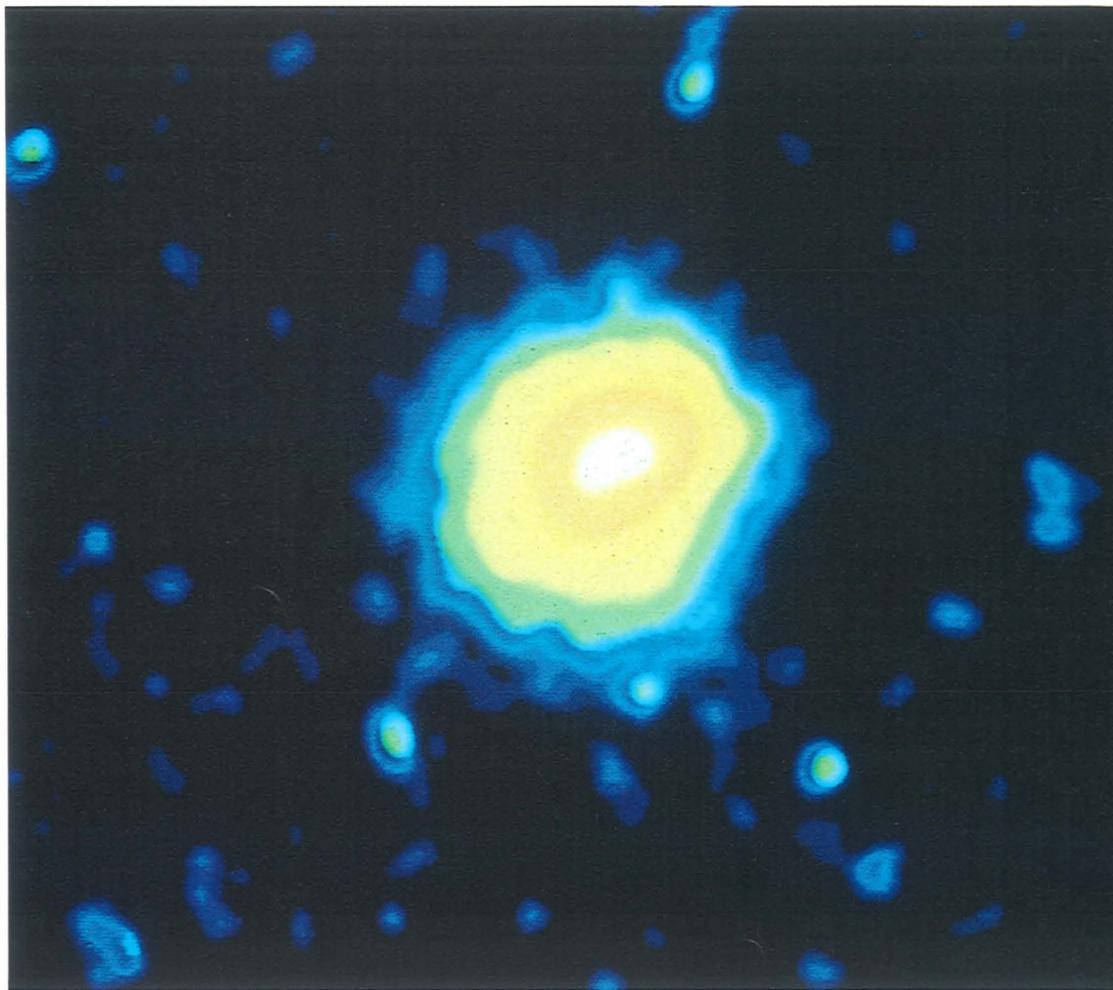
effects of solar energy on terrestrial systems also gain from improved understanding of the behavior of stars, especially our Sun. Scientific requirements of the AXAF are stimulating advances in optical sensors and imaging devices. Practical applications of this new technology include nondestructive X-ray tests for baggage inspection and medical diagnosis, as well as star trackers and sensors for guiding spacecraft.

The pre-eminent importance of the AXAF is its unique capability for scientific research. Never before have we had the opportunity to see as distantly or focus as sharply, in X-ray wavelengths, into the reaches of space. Nor have we had a chance for 10 to 15 years of uninterrupted X-ray observation. This opportunity for a long-term, detailed, systematic study of the entire universe is unprec-

edented. Observing high-energy processes in this cosmic laboratory, we expect important findings related to stellar and cosmic evolution, hidden mass, and the structure and dynamics of celestial objects. Though we cannot predict exactly what they will be, we are confident of discoveries.

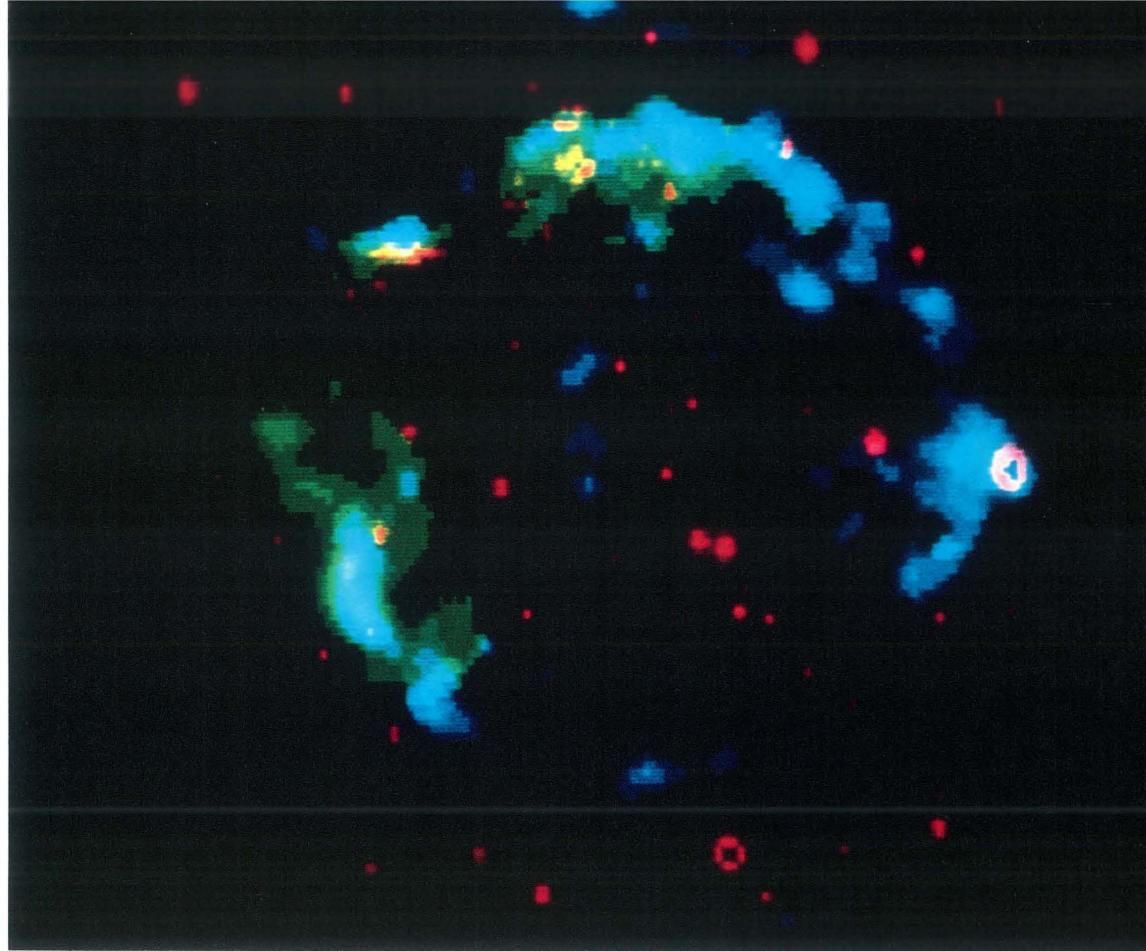
AXAF observations undoubtedly will have a profound impact on our concepts of the universe. We smile at the naivete of ancient models, imagined without the benefit of modern scientific instruments and methods. Perhaps in a few years our knowledge will increase so much that today's models will seem primitive. The Advanced X-Ray Astrophysics Facility carries forth our timeless query into the nature of the cosmos. With it, we continue to peer into the heavens, to imagine the universe. □

*In an optical image, this region of the sky would be dominated by stars. In this X-ray image, however, the field is dominated by objects outside the galaxy. The large image is the Abell 2256 cluster of galaxies. The smaller point-like objects probably are quasars.*



## Acknowledgments

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The Advanced X-Ray Astrophysics Facility enjoys widespread support within the scientific and technical community. Scientists from the following institutions have participated in a Science Working Group to advise NASA of the scientific goals, instruments, and potential uses of the new observatory:

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Naval Research Laboratory  
Pennsylvania State University  
Stanford University  
Tokyo University, Japan  
University of California, Berkeley  
University of Colorado  
University of Leicester, United Kingdom  
University of Texas  
University of Wisconsin

*A composite image of the Cassiopeia A supernova remnant combines information gained by three different techniques of astronomical observation. (Green: X-ray; Red: optical; Blue: radio)*

The AXAF Program is managed by the Marshall Space Flight Center for the Office of Space Science and Applications, National Aeronautics and Space Administration.

## Photograph and Illustration Credits

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Veil Nebula, U.S. Naval Observatory  
Andromeda Galaxy (X-ray), Smithsonian Astrophysical Observatory

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Normal Galaxy in Ursa Major, California Institute of Technology  
Active Galaxy (M82), U.S. Naval Observatory  
Radio Galaxy in Centaurus, California Institute of Technology  
Globular Star Cluster in Hercules, U.S. Naval Observatory  
Vela Pulsar, Smithsonian Astrophysical Observatory  
Quasar 3C273 in Virgo, Kitt Peak National Observatory  
Cassiopeia A (optical), California Institute of Technology

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Cassiopeia A (X-ray), Smithsonian Astrophysical Observatory

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Terzan 2 Burster, Smithsonian Astrophysical Observatory

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Andromeda (X-ray), Smithsonian Astrophysical Observatory  
Andromeda (optical), Celestron International  
Andromeda (X-ray), Smithsonian Astrophysical Observatory

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Quasar 3C47 (optical & X-ray), Smithsonian Astrophysical Observatory  
Quasar (artist's concept), Michael Carroll

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Quasar 3C273, Smithsonian Astrophysical Observatory

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Evolution of the Universe, NASA/Marshall Space Flight Center

### Page 20

Abell Cluster 2256, Smithsonian Astrophysical Observatory

### Page 21

Cassiopeia A (composite image), Smithsonian Astrophysical Observatory

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